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ON THE PHYSICS OF THE ATMOSPHERE.[1]

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INTRODUCTION.

THE physical phenomena of the earth's atmosphere are exceedingly numerous and often owe their origin to a plurality of causes. Nevertheless they can be just as accurately described and, in general, just as satisfactorily explained as can phenomena of the laboratory, from which, indeed, they differ but little save in extent and complexity. In fact, with but few exceptions, meteorological phenomena are wholly physical phenomena, and meteorology itself, as distinguished from climatology, a most interesting branch of applied physics. Happily, too, because of its valuable applications, it is a science that is rapidly being developed.

FUNDAMENTAL FACTS.

In what follows, the physical explanations of certain atmospheric phenomena will be briefly explained. But first, as a helpful introduction, it may be well to consider a sort of a cross

[1] Presented at the meeting of the Section of Aërial Navigation and Aëronautics held Thursday, January 23, 1913.

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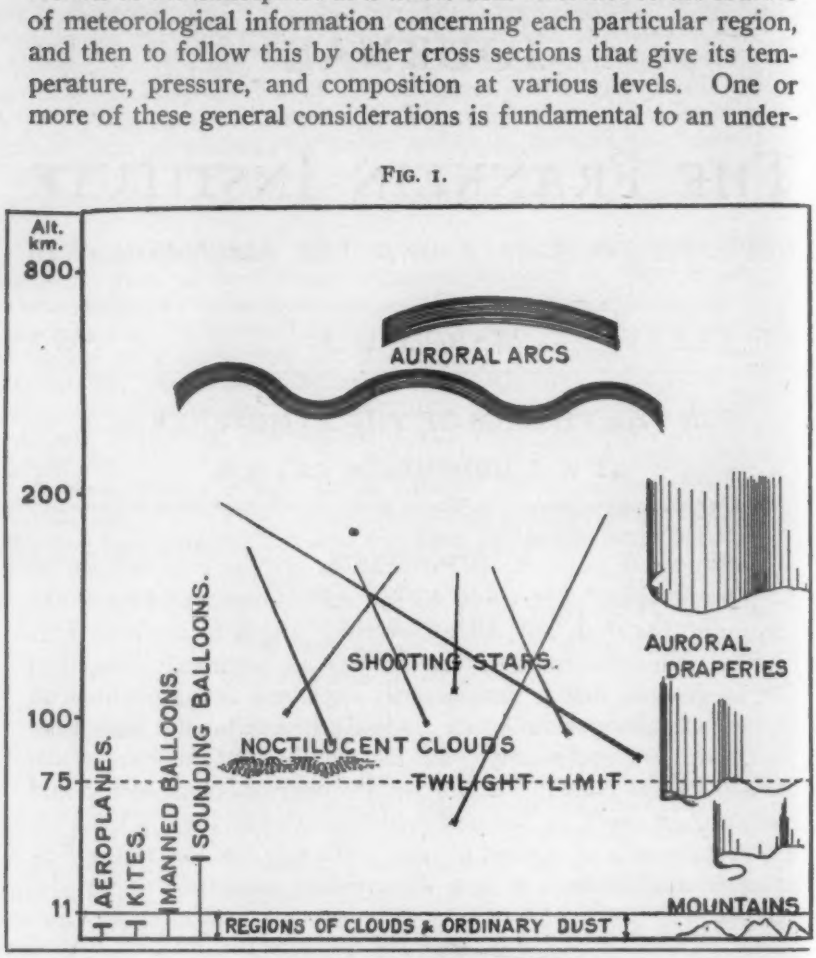
section of the atmosphere as a whole with reference to the sources of meteorological information concerning each particular region, and then to follow this by other cross sections that give its temperature, pressure, and composition at various levels. One or more of these general considerations is fundamental to an under-

FIG. 1.



Sources of meteorological information.

standing of almost any detail in the physics of the atmosphere, and hence they should constitute, as stated above, an introduction helpful to anyone who wishes to make a serious study of this important subject.

Sources of Information.—Fig. 1, an adaptation of Wegener's [1] Profile of the Atmosphere, indicates the principal

[1] *Phys. Zeitsch.*, 12 Jahrg. 1911, p. 170.

sources of meteorological information and the distribution of phenomena at various levels.

Mountains and other irregularities of the earth's surface enable us to explore the atmosphere from sea level up to about 7 kilometres, beyond which elevation man has not yet been able to climb. But, of course, in this case the surface conditions, whatever they may be, are always present, and hence some other means of gathering information must be adopted if we would know the conditions and movements of the free atmosphere. One obvious source of the desired information, and one that has been extensively used, is the movement of clouds, which, as is generally known, occurs at all levels from the land or ocean itself up to 11 kilometres, or thereabout, in middle latitudes and occasionally even as high as 15 kilometres in the tropics.

The elevation, direction of motion, and velocity of clouds are all easily determined by the aid of appropriate apparatus, and hence the direction and velocity of the wind at the same time and place are known. However, this is nearly all the positive information about the atmosphere that clouds do give, and besides they are by no means always present, so that on clear days even this information would be lacking if we had no other means of investigation. But then there are other means, and, in several respects, means far more valuable than the measuring of clouds, of gaining information in regard to the free air. The most valuable of these is the use of self-registering thermometers, barometers, hygrometers, and the like on:

(*a*) Aëroplanes; present limit about 6 kilometres.

(*b*) Kites; up to 7 kilometres.

(*c*) Manned balloons; maximum elevation roughly 11 kilometres.

(*d*) Sounding balloons; with a record of more than 30 kilometres.

The registering apparatus sent aloft by these various methods furnishes reliable information about the composition (including humidity), temperature, pressure, direction of motion and velocity of the atmosphere, from the surface of the earth up to the greatest elevations reached. And it is this automatically recorded information, gathered, with but little exception, during only the past few years, that has so greatly extended our accurate knowledge of meteorology, and done so much to make of it a thoroughly respectable branch of physics.

Beyond the reach of the sounding balloon, or at greater elevations than 30 kilometres, our information of the atmosphere is limited to such deductions as may properly be drawn from the height of the twilight arch, roughly 75 kilometres; the paths of shooting stars, rarely if ever seen as high as 200 kilometres; and the appearance and field of auroras, curious and but partially explained electrical discharges seldom occurring lower than 30 kilometres or higher than 300.

These, then, are all, or nearly all, the means by which our knowledge of the atmosphere has been obtained. Up to 30 kilometres it is comparatively well known; beyond that level only deduction, growing less certain with elevation, can possibly take us at the present, or any time until higher soundings are made.

Temperature Gradients.—We will now consider the temperature of the atmosphere at different levels, and as this varies more or less from day to day, as well as from place to place and season to season, averages will be given of values obtained by sounding balloons.

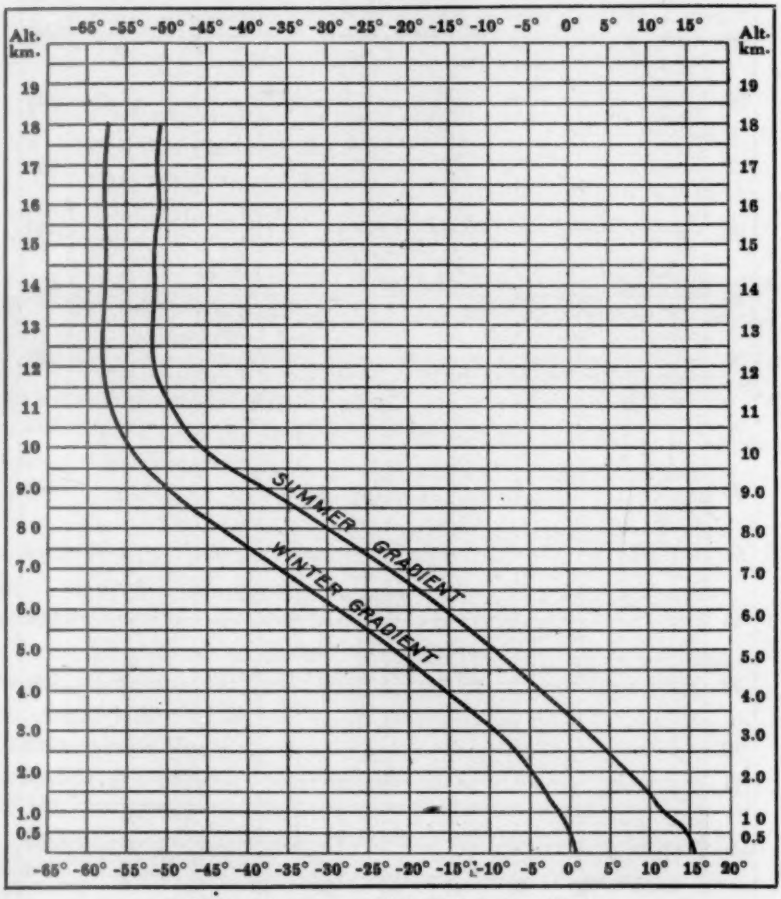
A curve obtained by plotting temperature against altitude is known as a vertical temperature gradient, and serves the purpose of showing graphically not only the actual temperature at any given altitude but also the rate and sense of change of temperature with change of altitude.

Fig. 2 shows both a winter and a summer vertical temperature gradient as determined by averaging 52 and 65 records, respectively, obtained by sounding balloons sent up from Munich, Strassburg, Trappes, and Uccle, all of which stations are comparable in the sense that they do not differ greatly in latitude and have more or less similar climates. A larger number of observations would give averages closer to the actual normal, but the general results certainly would remain the same. The two gradients, it will be observed, are roughly parallel throughout the entire region examined, except the lowest two or three kilometres, where the departure may easily be explained by the differences, in the two seasons, of the ordinary daily convection.

The vertical temperature gradient at any given time, as determined by sounding balloon records, differs more or less, as a rule, throughout its course, from the average or normal gradient. This difference, however, is not particularly misleading except in those upper levels (10 to 12 kilometres in the given figure)

where the average gradient shows a *gradual change* in the rate of temperature decrease. As a matter of fact, the actual transition from maximum to minimum rate of temperature decrease

FIG. 2.

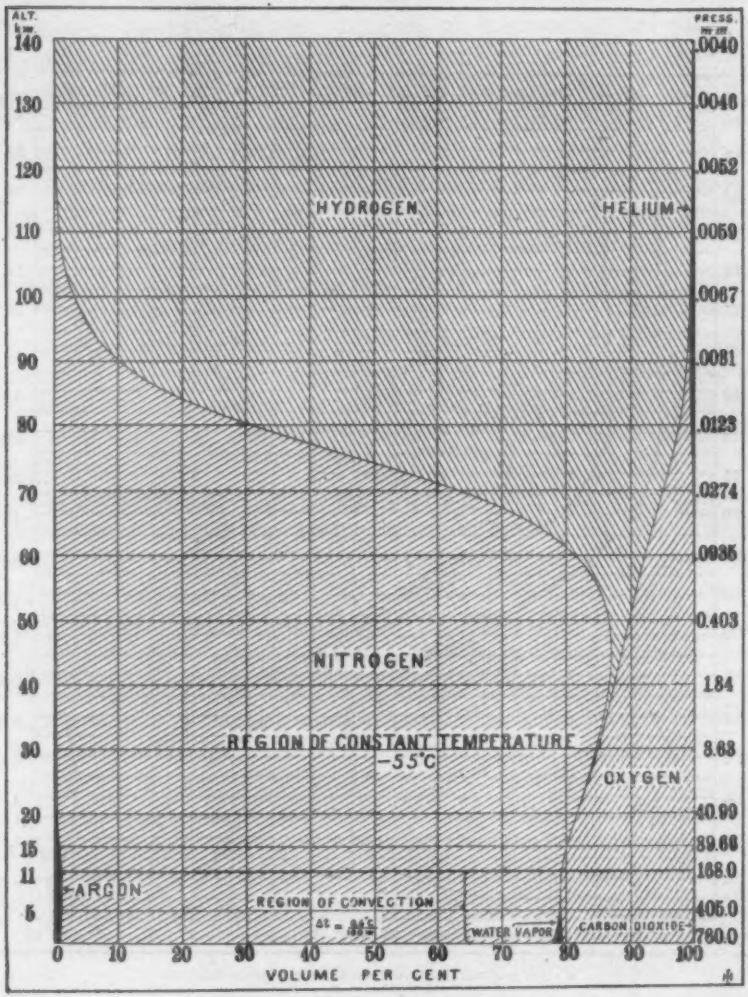


Winter and summer vertical temperature gradients.

usually is faster than the average gradient would indicate; indeed, it often is so quick as to appear abrupt, while in some cases it even inverts into a rapid, though generally slight, temperature increase. However, both the level and the temperature at which these rapid transitions take place vary from day to day, and hence,

on being averaged, a deceptively gradual and regular transition is indicated.

FIG. 3.



Composition of the atmosphere.

Composition of the Atmosphere.—Fig. 3, drawn in accordance with Table I, graphically represents the approximate composition of the atmosphere at various levels. The assumptions upon which it is based are in close agreement with the average conditions of middle latitudes, and are as follows:

1. That at the surface of the earth the principal gases of the atmosphere and their respective volume percentages in dry air are:

Nitrogen	78.03	Hydrogen	0.01
Oxygen	20.99	Neon	0.0015
Argon	0.94	Helium	0.00015
Carbon dioxide	0.03		

2. That water vapor at the surface of the earth amounts to 1.2 per cent. of the total quantity of gas present.

3. That the water vapor rapidly decreases, under the influence of lower temperatures, with increase of elevation, to a negligibly small amount at or below the level of 10 kilometres.

4. That the temperature decreases uniformly at the rate of 6° C. per kilometre from 11° C. at sea level to —55° at an elevation of 11 kilometres.

5. That beyond 11 kilometres above sea level the temperature remains constant at —55° C.

6. That up to the level of 11 kilometres the relative percentages of the several gases, excepting water vapor, remain constant—a result, of course, of vertical convection.

7. That above 11 kilometres, where the temperature changes but little with elevation, and where vertical convection, therefore, is practically absent, the several gases are distributed according to their respective molecular weights.

A number of atmospheric gases—neon, krypton, xenon, ozone, etc.—are omitted both from Table I and from its accompanying figure. This is because all these occur—in the lower atmosphere, at any rate—in quantities too small for graphical illustration in the same diagram and to the same scale as are the principal gases.

In using this diagram it should be distinctly remembered that it is supported by direct experimental observations only from the surface of the earth up to a level of about 30 kilometres, and that while the extrapolated values are based upon apparently sound logic and not upon mere surmises, still they necessarily become less and less certain with increase of elevation.

From the surface of the earth up to 11 kilometres elevation the variation of pressure with altitude must be computed according to Ferrel's or some similar equation that takes account of the effect of temperature change. But from this level on the

process is greatly simplified because of the constant temperature. Thus the percentage of each gas is multiplied by the total pressure at the elevation of 11 kilometres to find its own independent or partial pressure at that elevation, and its pressures at other elevations are then determined by the simple equation

$$-dB = B\frac{dh}{H}$$

in which dB is the change in the partial pressure due to the change dh in the elevation, B the initial partial pressure and H the virtual height of the gas in question or height, assuming its density throughout to be the same as at the given level, necessary to produce the pressure B. This neglects the change in the force of gravity with change of latitude and with change of elevation, but for a fairly close first approximation it is quite sufficient. It is not convenient, however, for numerical calculations, and therefore to adapt it to the computation of Table I it was put in the form

$$\text{Log}_{10} B = \text{Log}_{10} B' - \frac{0.434295}{H}(h - h')$$

This adapts the equation to the use of ordinary logarithms and renders the computations easy. H, of course, is different for different gases, but for each one it is known for any given temperature and pressure.

The table and the figure bring out a few points not generally realized. One of these is the fact that the total amount of argon in the atmosphere is much greater than the average total amount of water vapor. Another is the surprisingly small amount of water vapor, especially in view of the wonderful things it does, and of its vital importance to life of every kind. There may also be a little surprise that, according to calculation, the percentage of water vapor reaches a certain maximum at an elevation of 70 to 80 kilometres, where it is, roughly, twenty-fold what it is at, say, 11 kilometres. But this does not mean that the total amount of water vapor increases with elevation, but only that it decreases less rapidly than do the heavier constituents, and more rapidly than the two lighter ones, hydrogen and helium.

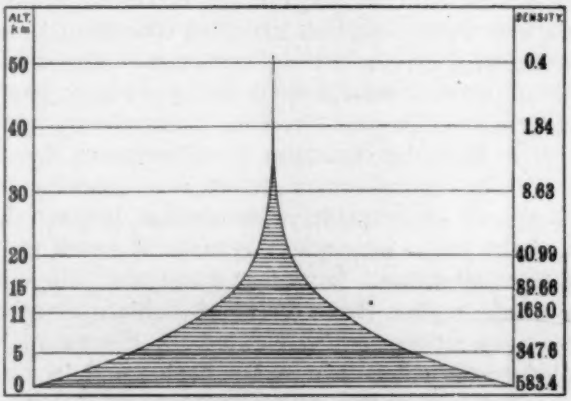
TABLE I.

Percentage Distribution of Gases in the Atmosphere.

Height in kilometres	GASES.							
	Argon.	Nitrogen.	Water vapor.	Oxygen.	Carbon dioxide.	Hydrogen.	Helium.	Total pressure in millimetres.
140	....	0.01	....	.....	....	99.63	0.36	0.0040
130	....	0.04	....	.....	....	99.55	0.41	0.0046
120	....	0.19	....	.....	....	99.35	0.46	0.0052
110	....	0.68	0.02	0.02	....	98.77	0.51	0.0059
100	....	2.97	0.05	0.11	....	96.31	0.56	0.0067
90	....	9.86	0.10	0.49	....	88.97	0.58	0.0081
80	....	32.39	0.17	1.86	....	65.11	0.47	0.0123
70	0.03	62.04	0.20	4.74	....	32.73	0.26	0.0274
60	0.03	81.33	0.15	7.70	....	10.69	0.10	0.0935
50	0.12	86.82	0.10	10.17	....	2.76	0.03	0.403
40	0.22	86.43	0.06	12.61	....	0.67	0.01	1.84
30	0.35	84.27	0.03	15.18	0.01	0.16	....	8.63
20	0.59	81.24	0.02	18.10	0.01	0.04	....	40.99
15	0.77	79.52	0.01	19.66	0.02	0.02	....	89.66
11	0.94	78.02	0.01	20.99	0.03	0.01	....	168.00
5	0.94	77.89	0.18	20.95	0.03	0.01	....	405.
0	0.93	77.08	1.20	20.75	0.03	0.01	....	760.

Density of the Atmosphere.—Fig. 3, though serving the useful purpose of graphically representing the percentage distribu-

FIG. 4.



Density of the atmosphere.

tion of the several gases of the atmosphere, is nevertheless likely to be misleading in respect to their combined density, especially at great elevations. This latter information is shown by Fig. 4, in

which the width at every altitude is proportional, approximately, to the corresponding atmospheric density, or at least to as great an elevation, about 40 kilometres, as the size of the figure will permit. Indeed, the density decreases so rapidly with increase of elevation that if at the level of 140 kilometres it is represented by a line only one one-hundredth of an inch long, then at sea level, taking into account difference in temperature and in composition, it would require for its full representation to the same scale a line whose length was, roughly, 1800 feet. Obviously, therefore, the density of the atmosphere throughout its known range of, say, 250 kilometres cannot be graphically represented on any one scale.

THE ISOTHERMAL REGION.

One of the above introductory or fundamental graphs, Fig. 2, represents information but recently acquired, and itself needs interpretation. Indeed, the discovery of the fact that the temperature of the upper atmosphere changes but little with altitude, and the supplementary discovery of its physical explanation, constitute probably the most important advances in modern meteorology.

About a dozen years ago Teisserenc de Bort began sending up free balloons with self-registering thermometers, and soon found temperature records that indicated something unsuspected: either unsuspected errors in the thermometers themselves or unsuspected temperature conditions in the upper atmosphere. However, numerous temperature records subsequently obtained by Teisserenc de Bort, by Assmann, by Hoormann, by Rotch, by Petavel, and by many others in various countries and with different kinds of apparatus have shown that, in general, the temperature of the upper atmosphere actually does change but little with change of elevation. Indeed, as a rule, the change is so small that the whole region characterized by this approximate constancy of temperature has been called the "isothermal region."

The height at which this region begins and its temperature both depend upon season, upon storm conditions, and upon latitude; but, while all these are important details, they are secondary to the fact that there is an isothermal region at all. As soon as observations left no doubt of the actual existence of the isothermal region many hypothetical explanations of it were

suggested, but for a number of years all such suggestions proved unavailing. Finally, however, independently and nearly simultaneously, the generally-accepted explanation occurred to Gold [2] of England and to Humphreys [3] of America. The key to their explanation is this: The temperature of every portion of the atmosphere is determined, in part at least, by counteracting radiation, by radiation absorbed, and by radiation emitted, and wherever these two are equal there is substantial constancy of temperature.

Mr. Gold's method of procedure was to take the best-known data concerning atmospheric absorption and radiation and to obtain, by the aid of suitable mathematics, a general solution of the problem. The chief difficulty in the application of this direct and elegant method, apart from the troublesome equations involved, is due to our imperfect knowledge of the necessary radiation and absorption constants. Numerical values in these particulars are not accurately known and certainly are not easy to determine.

On the other hand, the solution offered by Humphreys, while not so straightforward and direct, reduces the necessary mathematics to almost a zero minimum. In brief it is as follows: Since the average yearly temperature of the atmosphere at any given place does not greatly change, it follows that the absorption of solar radiation by the earth as a whole is substantially equal to the total of outgoing earth radiation, and in amount approximately equal to that which a blank or perfectly radiating surface, equal in area to the surface of the earth, would emit when at the absolute temperature 259° C.[4] Further, since at ordinary atmospheric temperatures water vapor, in any considerable quantity, absorbs and, presumably, also radiates substantially as does a black body at the same temperature, while dry air is exceedingly diathermanous, it follows that the planetary radiation of the earth is essentially water vapor radiation.

Now the records of sounding balloons show that at some altitude, in general about 11 kilometres above sea level in middle latitudes, the average temperature ceases to decrease with in-

[2] *Proc. Roy. Soc.*, Series A, vol. 82, 1909, p. 43.

[3] *Astrophys. Jour.*, vol. 29, 1909, p. 14.

[4] Abbot and Fowle, Annals of the Astrophysical Observatory of the Smithsonian Institution, vol. 2, p. 174.

crease of elevation. Individual flights show many peculiarities that call for special explanation, but the purpose here is to consider only the general explanation of the main effect, and therefore average conditions are considered.

If, then, as is approximately true, the temperature does not decrease with increase of altitude above 11 kilometres, it follows that this must be the limit of anything like a marked vertical convection. And from this in turn it follows that the upper atmosphere must be warmed almost wholly by absorption of radiation, in part solar and in part terrestrial; but exactly how much of the final temperature of the upper atmosphere is due to the one source of heat and how much to the other it is not possible to say. However, there are certain facts that seem clearly to indicate the relative importance of the two. Thus the summer and winter gradients as given by Fig. 2 show a difference of temperature in the isothermal region of only about the amount that might be expected on the assumption that the temperature of the upper air is wholly dependent upon the radiation from the lower. That is to say, the seasonal temperatures of the lower atmosphere differ distinctly more than do those of the upper. It should be distinctly remembered, too, that the particular seasonal gradients given in Fig. 2 were obtained at a latitude of, roughly, 50° where the number of hours of summer and winter sunshine differ greatly, and therefore where the seasonal temperature of the isothermal region, if essentially determined by absorption of solar radiation, should differ somewhat correspondingly. But as no such great difference in these temperatures does exist, it would appear that the temperature of the isothermal region must be due chiefly to absorption of long wavelength radiation given off by the water vapor and other constituents of the atmosphere at lower levels. Hence, as a first approximation, we will consider this radiation alone, and for the lower atmosphere as it actually exists we will substitute the radiationally equivalent black shell at the absolute temperature of 259° C. Obviously, too, this surface, surrounding as it does the entire earth, may be regarded as horizontal and of infinite length and breadth in comparison to any elevation attainable by sounding balloons.

Now consider two such surfaces, parallel and directly facing each other, with distance apart small in comparison to their width,

and having the same absolute temperature T_2, and let an object of any kind whatever be placed at the centre of the practically enclosed space. Obviously, according to the laws of radiation, the final temperature of the object in question will also become approximately T_2. If now one of the parallel planes should be removed, the exposed object would be in substantially the same situation, so far as exposure to radiation is concerned, as is the atmosphere of the isothermal region in its exposure to the radiation from the lower atmosphere. Hence the problem is to find the final temperature to which an object, assumed infinitesimally small, to fit the case of a gas, will come when exposed to the radiation of a single infinite black plane.

In each case,—that is to say, when between the parallel planes and when facing but one,—temperature equilibrium is reached when the loss of energy by radiation is equal to its gain by absorption. Also, so long as the chemical nature of the object remains the same, its coefficient of absorption is but little affected by even considerable changes in temperature, and therefore, whatever the nature of the object, since it is exposed to twice as much radiation when between the two planes as it is when facing but one, it must, in the former case, both absorb and emit twice as much energy as in the latter. Or, using symbols,

$$E_2 = 2E_1$$

in which E_2 and E_1 are the quantities of heat radiated by the object, per second, say, when between the two planes and when facing but one, respectively.

Again

$$E_2 = K_2 T_2^{n_2}$$

and

$$E_1 = K_1 T_1^{n_1}$$

in which T_2 and T_1 are the respective absolute temperatures of the object under the given conditions, and K and n the radiation constants.

For every substance there are definite values of K and n which, so long as the chemical nature of the object remains the same,

do not rapidly vary with change of temperature. Hence, assuming $K_2 = K_1$ and $n_2 = n_1$, we have, from the equation

$$E_2 = 2E_1$$
$$T_2 = \sqrt[n]{2}\, T_1$$

From this it appears that there must be some minimum temperature T_1 below which the radiation of the lower atmosphere will not permit the upper atmosphere to fall, though what it is, for a given value of T_2, depends upon the value of n.

Presumably the radiation of the upper atmosphere is purely a thermal radiation, and therefore in full agreement, as is the thermal radiation of water vapor, carbon dioxide, and certain other gases, with the Kirchhoff law.[5] In other words, the ratio of emission to absorption for any given wave-length, presumably, is wholly a question of temperature and is numerically equal to the radiation of a black body at the same temperature and wave-length. In symbols

$$\left(\frac{He}{h}\right)_{\lambda,t} = (E)_{\lambda,t}$$

in which H is the incident energy, h the energy absorbed, and e the energy emitted by the body or gas in question at the wave-length λ and temperature t, and E the black body emission at the same wave-length and temperature, all per equal area and time.

To fix the ideas, let the body of gas under consideration be a shell one centimetre thick, surrounding the earth at a fixed distance—20 kilometres, say, above sea level—and let the black body be an infinitely thin shell and therefore at the same temperature inside and out, that may, if we wish, take the place of the gas shell. We can now consider the incident radiation to be normal if we like, on one side, and the emitted radiation to be all the energy sent out by the shell on *either* or on *both* sides; only, whatever the assumption for one shell, the same must be made for the other.

Returning to a consideration of the temperature of the upper atmosphere under the influence of radiation from the lower gases:

Since the composition of the upper atmosphere is not ap-

[5] Pringsheim, *Congrès International de Physique*, Paris, 1900, vol. 2, p. 127.

preciably changed by a change of even 50° C., it follows that such a change of temperature will not materially alter its coefficient of absorption. Hence a change in the intensity of the incident radiation H will make substantially the same proportionate change in the rate of absorption h, whatever the alteration in temperature. In short,

$$\frac{H}{h} = K, \text{ a constant, presumably.}$$

Hence

$$\frac{e_{\lambda,t_1}}{e_{\lambda,t_2}} = \frac{E_{\lambda,t_1}}{E_{\lambda,t_2}}$$

or

$$\frac{e_{\lambda,t_1}}{E_{\lambda,t_1}} = \frac{e_{\lambda,t_2}}{E_{\lambda,t_2}}$$

Unfortunately, nothing is known of the spectral distribution of the energy radiation of the cold upper atmosphere, though possibly it is of the irregular, but more or less continuous, broad band type. If this is its distribution and if for each wave-length the increase of black body radiation, for a small increase of temperature, is proportional to the total radiation at that wave-length which it is to a rough first approximation, then to about the same average approximation

$$\frac{e_{t_1}}{e_{t_2}} = \frac{E_{t_1}}{E_{t_2}},$$

in which the symbols stand for the total radiation of all wave-lengths.

But from the Stefan law in regard to the total radiation of black bodies, we know that

$$\frac{E_{t_1}}{E_{t_2}} = \frac{T_1^4}{T_2^4}$$

in which T_1 and T_2 are the respective absolute temperatures.

Hence, if, as explained above, the spectral distribution of the radiation of the upper atmosphere is continuous, or nearly so (no matter how irregular), and not confined chiefly to lines, with zero radiation between them, it follows that in the equation

$$T_2 = \sqrt[n]{2}\ T_1,$$

the numerical value of n must be 4, roughly. But, as already explained, the value of T_2 is substantially 259° C. absolute; hence, on the assumption that $n=4$, it follows that $T_1=218°$ C. absolute. And this is the value, approximately, that observation gives.

Whatever the facts in regard to the radiation constants of the atmosphere, the laws of radiation and absorption demand that the temperature of the upper atmosphere shall change but little with change of elevation. Besides, while the exact value of this temperature—the temperature of the isothermal region—is, of course, best determined by actual observation, it also may be approximately computed from the known intensity of outgoing radiation, together with the thermal properties of the gases of the atmosphere.

Doubtless solar radiation affects the temperature of the isothermal region to some extent, but, presumably, not very much, since the radiation from the lower levels seems competent not only to produce an isothermal condition in the upper levels but also to maintain them at approximately the observed temperature.

Given the isothermal condition of the upper atmosphere, it follows that the heated surface air can, under favorable circumstances, rise till, but only till, by expansion it has cooled down to that temperature (the temperature of the isothermal region) below which the radiation from the lower atmosphere will not allow it to fall.

The existence of an upper isothermal region and the vertical temperature gradient (Fig. 2) suggest rational explanations of a number of otherwise obscure meteorological phenomena,—why the clouds of a given region have a fairly well defined maximum elevation, why this elevation is greater in summer than in winter, why there are three levels, and only three, of maximum cloud formation, and the like,—but, though interesting, all these are secondary phenomena, and therefore a further discussion of them will be omitted.

PERMANENT OCEAN HIGHS.

Next after the above consideration of conditions that limit the vertical movements or convection of the atmosphere it may be convenient to examine some of the chief factors in the control

FIG. 5.

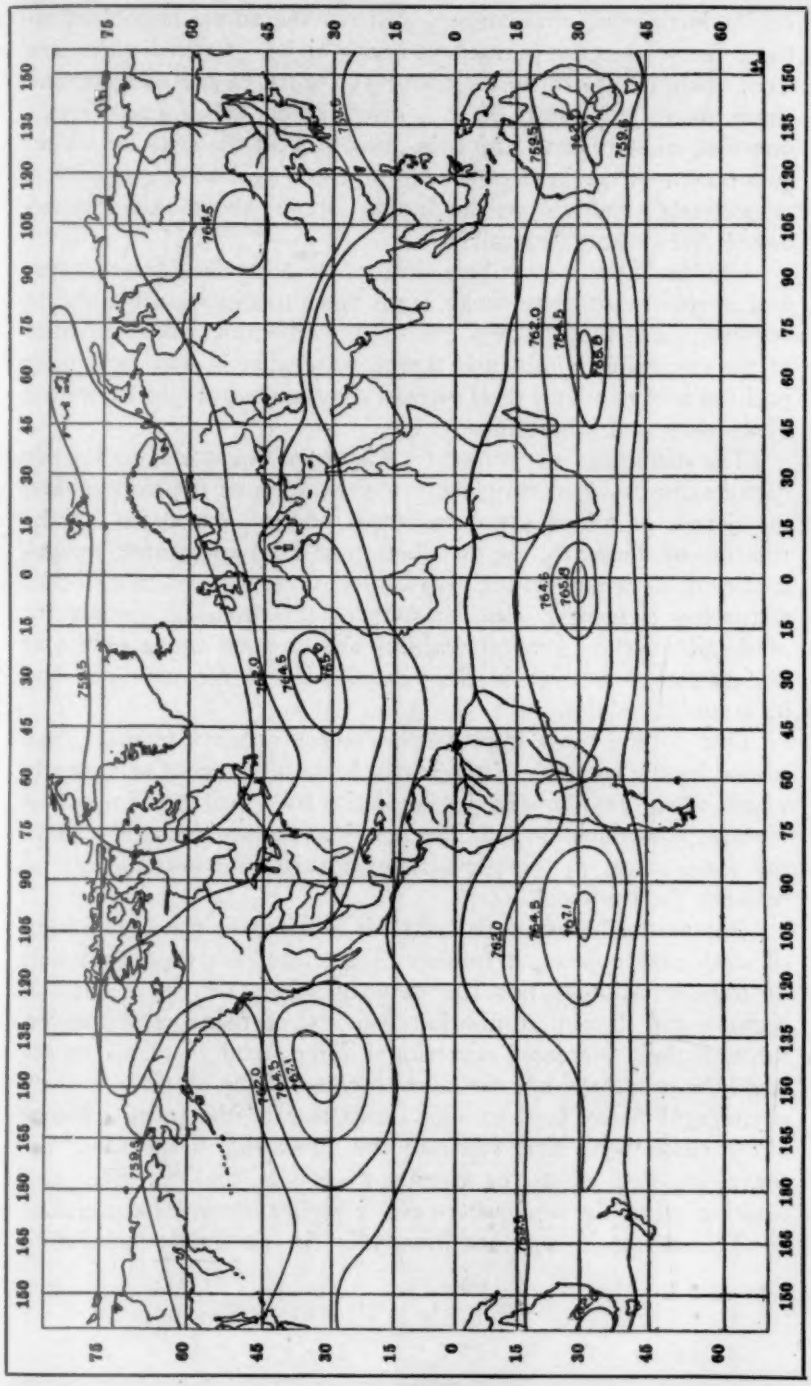


Fig. 5.

Annual average isobars.

of its horizontal circulation. Among the more important of these factors are the permanent ocean highs, of which there are five: two, as Fig. 5 shows, about 35° north of the equator, and three about 32° south of it. Two are on the Pacific Ocean, one west of southern California, the other off the coast of Chile; two on the Atlantic Ocean, near Morocco and southern Africa, respectively; and one on the Indian Ocean, about half way between Africa and Australia.

Obviously there must be a close relation between the positions and intensities of these ocean highs and the climates of adjacent regions, since they largely control the directions and velocities of the encircling winds, and therefore what it is that fixes their position and regulates their intensity is a meteorological question of fundamental importance.

The difference in temperature between equatorial and polar regions causes a general planetary circulation of the atmosphere, the details of which are complicated beyond expression by the rotation of the earth, the distribution of land and water, irregularities in elevation, erratic distribution of clouds, and many other disturbing elements. But, in spite of this hopeless complexity of details, certain general features are obvious enough, just as the course of a river is clear despite its numerous turns and its countless eddies.

One of the most important of these general features, one caused by the rotation of the earth, is the prevalence of westerly winds along middle and higher latitudes. Another important feature, complementary to the one just mentioned, and due to the same cause, is the prevalence of easterly winds along and between the trade belts.

But as the bulge of the earth is adapted to the equilibrium of stationary objects, it follows that neither the westerly winds of middle latitudes nor the easterly winds of the equatorial regions can be in equilibrium on its surface. The former, through their increased centrifugal force, tend to climb up toward the equator, while the latter, because of the decrease in their centrifugal force, tend to slide down toward the poles. Hence along those belts that separate the prevailing west from the prevailing east winds, or about 30°–35° N. and S., there is a banking up of the atmosphere and a higher barometric pressure.

This, then, in a general way, is the accepted explanation

FIG. 6.

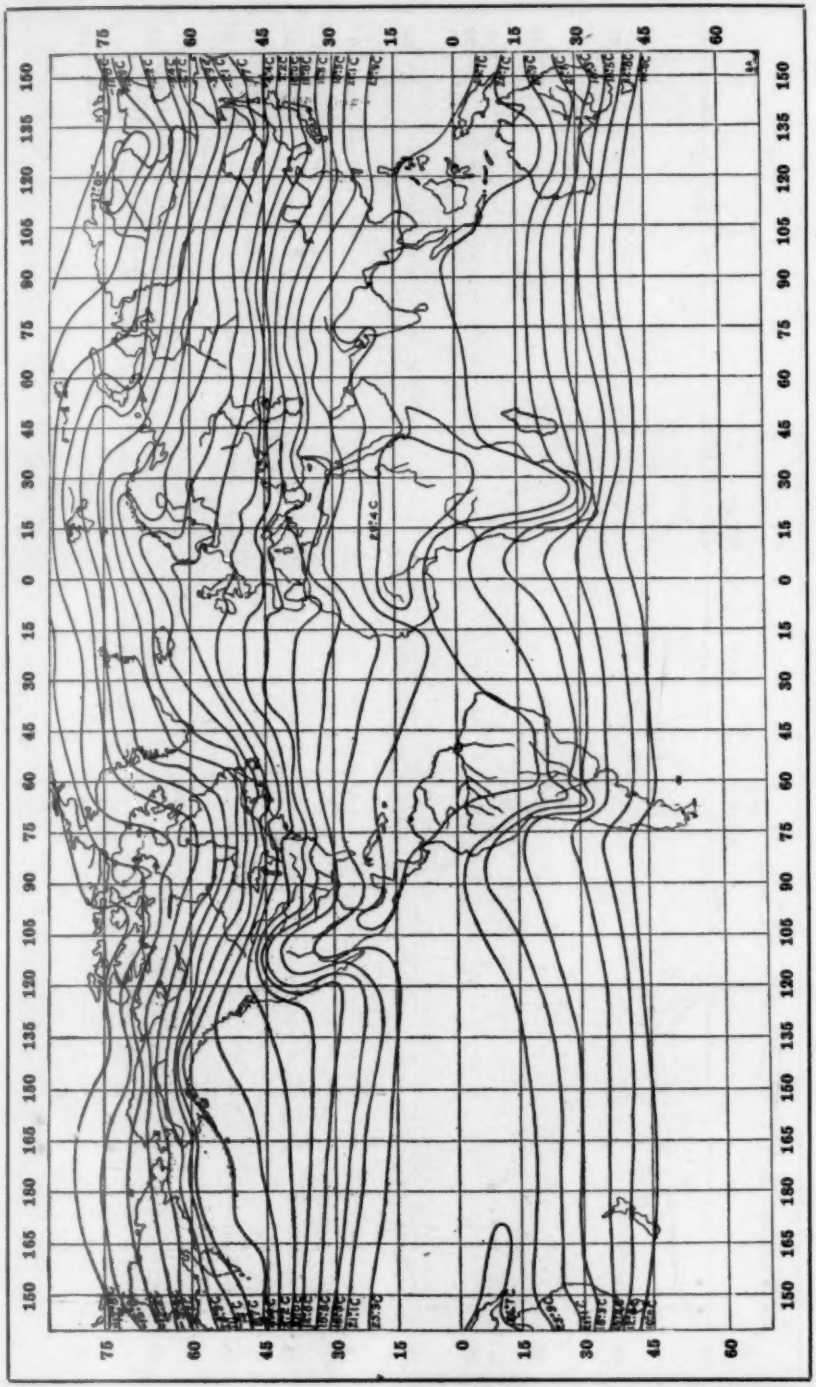
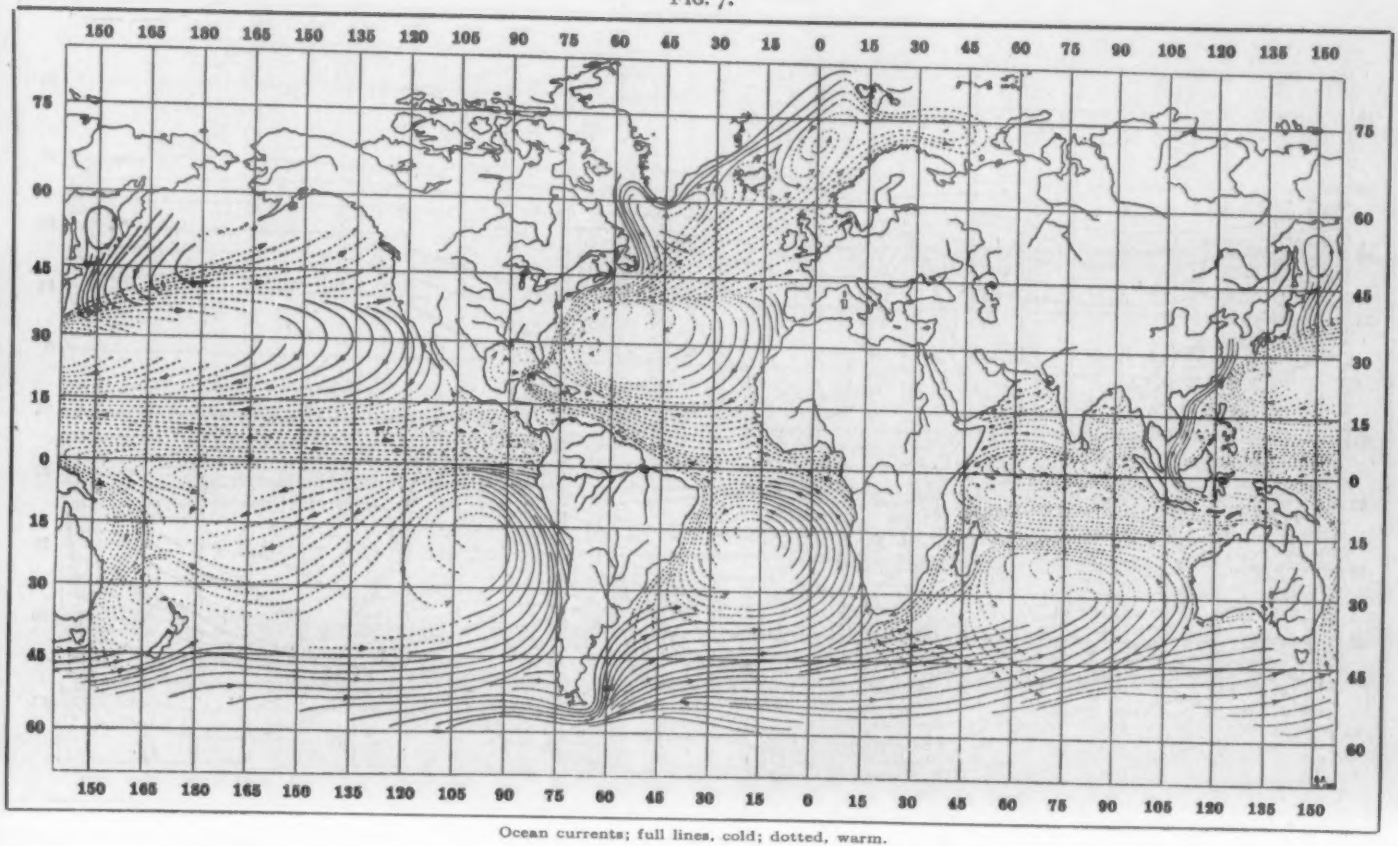


FIG. 6.

Annual average isotherms.

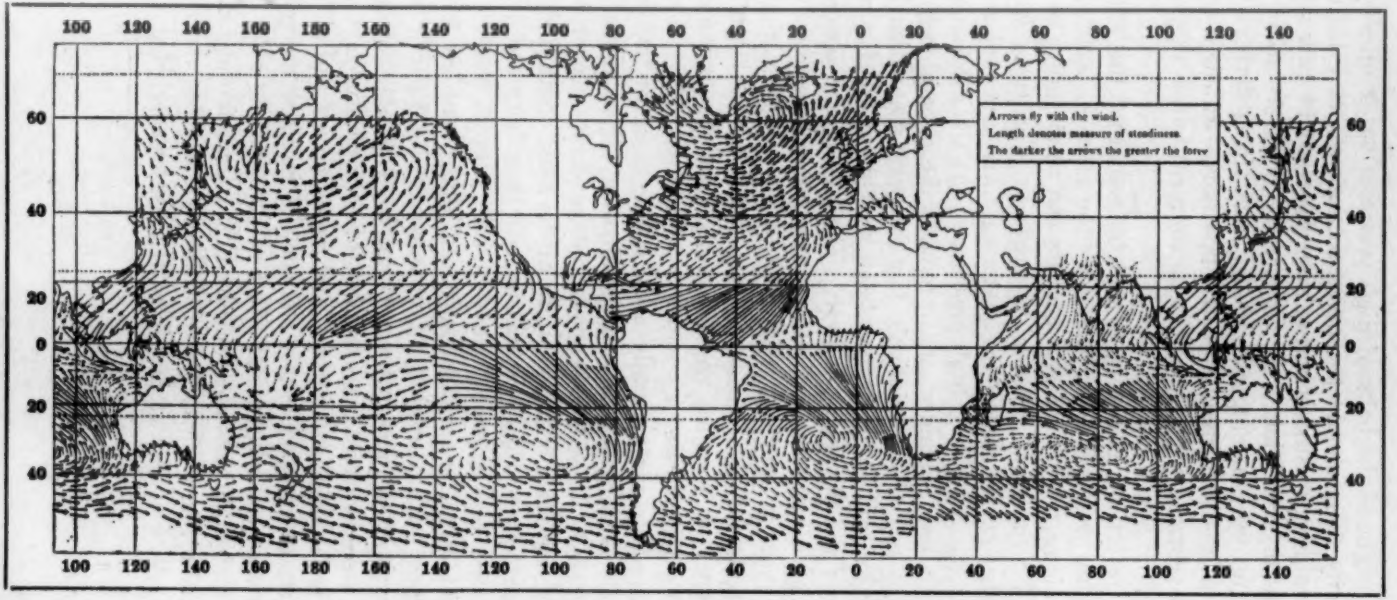
FIG. 7.



Ocean currents; full lines, cold; dotted, warm.

Ocean currents; full lines, cold; dotted, warm.

FIG. 8.


100 120 140 160 180 160 140 120 100 80 60 40 20 0 20 40 60 80 100 120 140
60
40
20
0
20
40
Arrows fly with the wind.
Length denotes measure of steadiness.
The darker the arrows the greater the force

Ocean winds, January, February.

of the origin of the belts of high pressure, but it offers no hint as to why there should be special sections of these belts where the prevailing pressure is higher than elsewhere in their neighborhood in any direction. Of course, the belts are more or less broken up by the temperature and other irregularities of continents over which they pass, but this is not sufficient to create distinct centres of highs, nor to locate them where they actually occur.

By referring to Fig. 5 it will be seen that the regions of maximum pressure, as indicated by the isobars, occur at those places *along the belt of highs* where the temperature of the air is low for the given latitude, as shown in Fig. 6, or where the air isotherms are deflected equatorward. At these places, then, there are two causes of high pressure: (*a*) the mechanical pressure, as above explained, that produces the general belt of high pressure, and (*b*) a relatively low temperature, which leads to contraction of the superincumbent air column, and a resultant inflow of the upper atmosphere. The two causes operating together give local maxima of pressure, which, as Figs. 8 and 9 show, exert at least a partial control on the circulation of the atmosphere for great distances roundabout, and in large measure determine the weather and types of climate of a considerable portion of the earth.

But what, one naturally asks, is the cause of the persistent relatively low temperature of the air over the particular regions in question? This, too, is answerable, and the answer furnishes the real explanation of the origin of the fixed ocean highs.

Referring to Fig. 7, it will be seen that there are five different places, and only five, where a cold ocean current crosses a belt of high barometric pressure, and that every one of these is associated with a region of maximum atmospheric pressure. Neither is there a permanent ocean high at any region except where a cold current crosses a belt of high pressure.

It is the cold water, then, that cools the air and allows it to contract, and wherever this tendency to increase the pressure is joined with the mechanical effect to produce the *belts* of highs, there, and only there, as shown by Fig. 10, are found a maximum of pressure, and the centre of a more or less permanent anticyclone. As a matter of fact in each case, because of the reaction

of the anticyclonic circulation, the highest pressure occurs a little to the west of the region of lowest temperature.

The ocean currents, in turn, are caused by winds, rotation of the earth, deflecting barriers, and a number of other contributing elements; hence there exists between all these phenomena a complex interrelation of cause and effect, of action and reaction, that cannot always be wholly disentangled. But this does not invalidate the sufficiency of the above explanation of the origin of ocean highs.

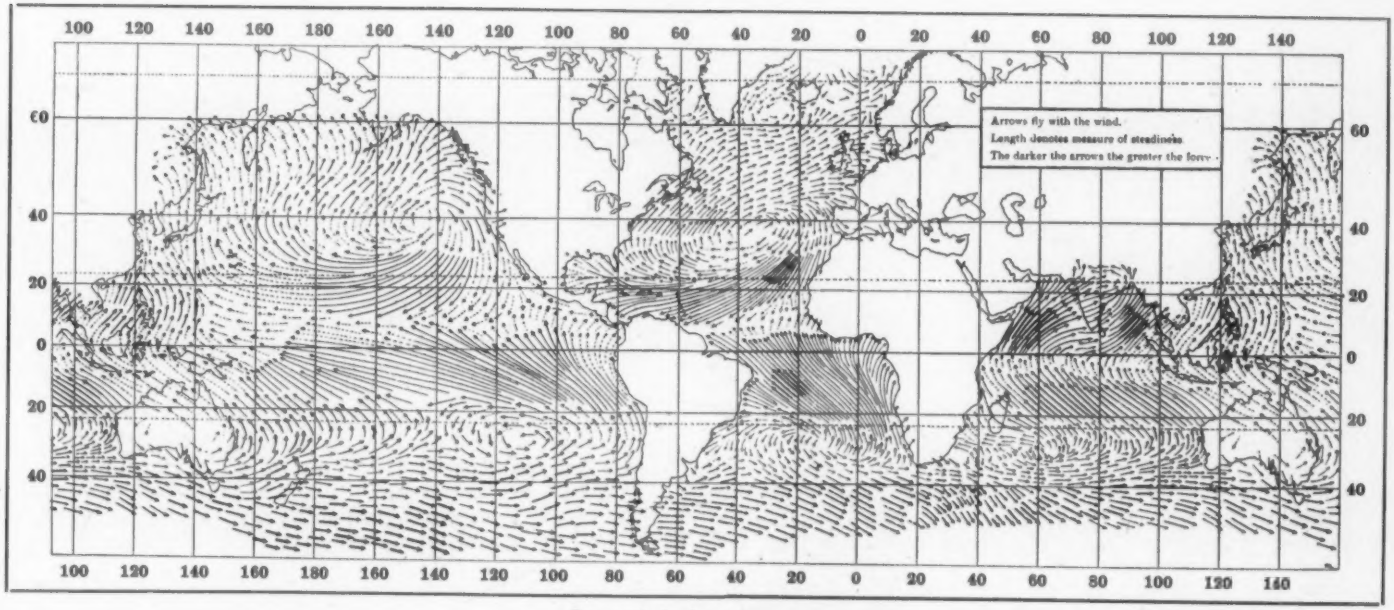
WIND STRUCTURE.

In addition to the phenomena of the general circulation of the atmosphere, a great deal of attention is now being given to the structure of air currents at different levels and under different conditions; partly because of its importance as a meteorological problem, but especially on account of its vital interest to aëronautics. Fortunately, too, while the details of air turbulence, like the turmoil of water rapids, are hopelessly beyond the power of theory fully to solve, the larger and relatively more important features give results in satisfactory agreement with rational theories, and are therefore predictable from certain known, or at least knowable, antecedent conditions.

General Wind Movement.—Obviously, every wind is caused by a pressure difference in the atmosphere along gravity equipotential surfaces. The fact that this difference, in turn, owes its origin almost wholly to temperature inequalities is for the present of no importance. For convenience, consider that one of these equipotential surfaces which coincides with the ocean surface. Now let a pressure difference be somehow established between a certain place and a neighboring region. At once the atmosphere begins to move from the region of higher toward the region of lower pressure, with an acceleration proportional to the pressure gradient, or ratio of pressure change to distance.

At first it might seem that the atmosphere would flow from the region of higher directly to the region of lower pressure, and thus quickly reëstablish a condition of pressure equilibrium. But this simple result never happens, because, as soon as the flow begins, new forces become immediately operative: one due to the rotation of the earth, another due to centrifugal action, and a third caused by friction and viscosity.

FIG. 9.


100 120 140 160 180 160 140 120 100 80 60 40 20 0 20 40 60 80 100 120 140
60
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20
0
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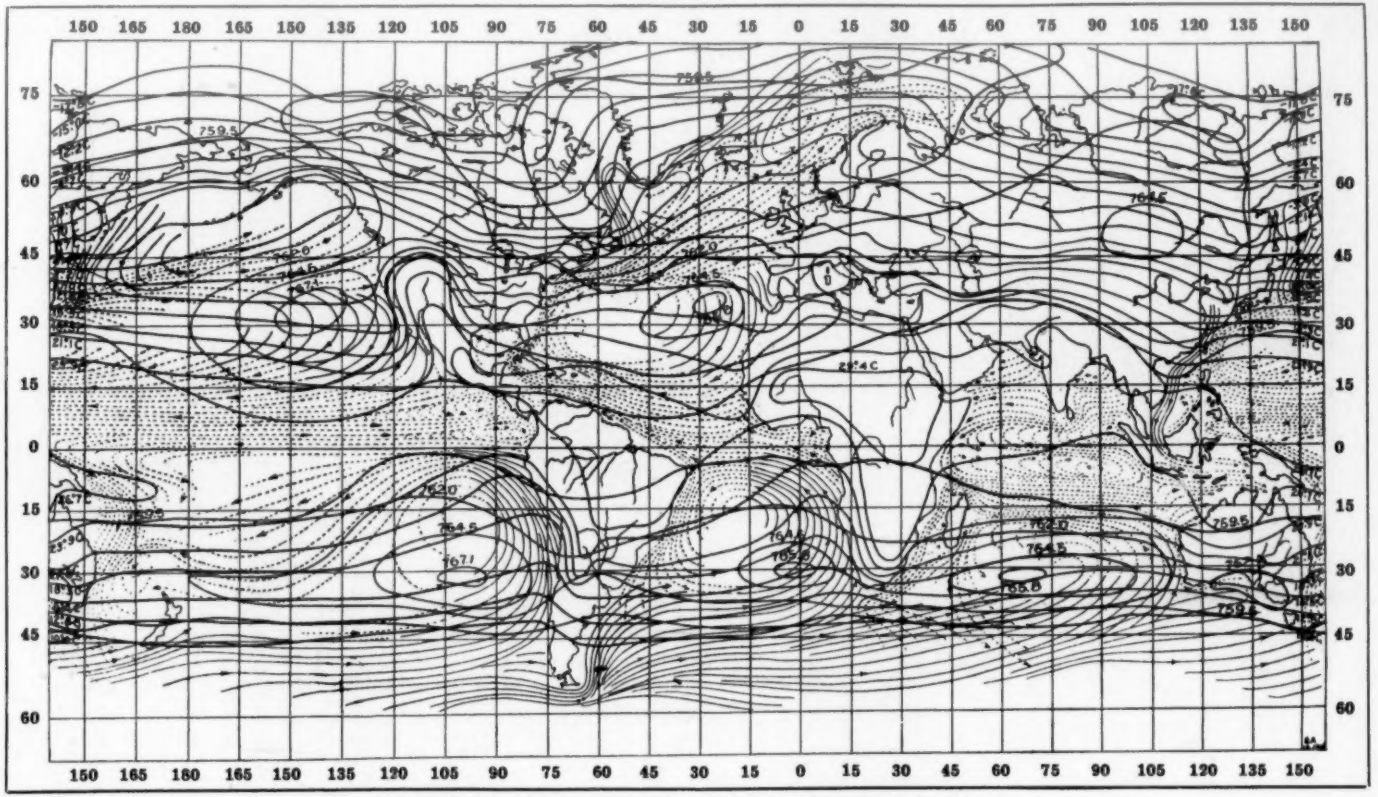
Arrows fly with the wind.
Length denotes measure of steadiness
The darker the arrows the greater the force

Ocean winds, July, August.

FIG. 10.



Superposition of ocean currents on annual average isotherms and isobars.

At a kilometre and more above the earth's surface frictional effects generally are negligible, and therefore for such altitudes we can write, as may be shown, the equation

$$g = \rho\left(2\omega v \sin\phi \pm \frac{v^2}{r}\cos\beta\right)$$

in which g is the pressure gradient, or the ratio of the pressure change to distance at right angles to the isobar passing through the place in question, ρ the density of the atmosphere, ω the angular velocity of the earth, v the velocity of the wind, r the radius of curvature of its path, β the angle between the plane of this path and the plane of the horizon, and ϕ the latitude. Further, the plus sign applies to cyclonic circulation, clockwise in the southern hemisphere and counter clockwise in the northern, and the negative sign to the reverse or anticyclonic circulation.

In this case (absence of friction) equilibrium is established not by a restoration of equal pressure, but by the production of a wind along the isobars of such velocity that the deflecting force shall be equal to the pressure gradient.

Except in the case of tornadoes, the second term in the parenthesis is small in comparison with the first. That is, the centrifugal force, except in extreme cases, is small in comparison with the deflective force due to the rotation of the earth. Hence, ordinarily we can write, as a close approximation,

$$v = \frac{g}{2\omega\rho\sin\phi}$$

Owing to friction of the atmosphere on the surface of the earth, and, in some measure, to its viscosity, the actual surface velocity of the wind is nearly always less than the calculated gradient velocity, and also more or less inclined to the direction of the isobar passing through the place in question; the inclination being toward the region of lowest pressure.

For a considerable elevation, both the gradient pressure and the density of the atmosphere decrease at about the same rate, and therefore the wind velocity commonly increases and its direction gradually changes, each at a nearly uniform rate, with increase of elevation, till at the height of 1200 metres the gradient velocity is approximately reached, and the direction becomes substantially parallel to the local isobar.

Hence the above gradient velocity equation is of special importance to aëronauts, in that it gives the velocity of the wind

as well as its direction (along the isobar) that may be expected at even moderate altitudes.

As a matter of convenience to the aëronaut, it may be well to substitute numbers for symbols in the velocity equation, and to show how, by the aid of this equation, he may profitably use the daily weather map as an indicator of the winds to expect should he go aloft. In this numerical substitution the needs of the largest number of aëronauts will best be met by expressing the velocity in terms both of metres per second and of miles per hour.

Using the C. G. S. system of units, we have the equation:

$$\frac{\text{centimetres}}{\text{seconds}} = \frac{\text{change in dynes per square centimetre per centimetre horizontal distance at right angles to isobar}}{2\omega\rho \sin \phi}$$

To make the problem definite, let isobars be drawn for each millimetre difference in barometric pressure, and let the shortest distance between the isobars at the place where the gradient wind velocity is desired be 100 kilometres, and let the latitude of the place be 40°.

Now the density of mercury is approximately 13.6. Hence a column of mercury one millimetre high and one square centimetre in cross section weighs 1.36 grammes, or $980 \times 1.36 = 1332.8$ dynes. In the assumed case, therefore, of a difference in barometric reading of one millimetre per 100 kilometres the pressure gradient is $1332.8/10^7 = 13328 \times 10^{-8}$.

Further,

$$\omega = \frac{2\pi}{86400} = \frac{\text{the number of unit angles in a circumference}}{\text{the number of seconds in 24 hours.}}$$

$\rho = .0012$, the density of air under normal conditions.
Sin $40° = .64279$.

Hence,

$2\omega\rho \sin 40° = 1122 \times 10^{-10}$, about,

and finally

$$v = 13328 \times 10^{-8} / 1122 \times 10^{-10} = 1188 \frac{\text{centimetres}}{\text{second}}$$

or 11.88 metres per second.

Hence, along or near the parallel of 40° the gradient velocity, in metres per second, for any given time and place, is, to a first approximation,

$$12n/K$$

in which n is the difference in millimetres between the readings of the nearest isobars to the place in question, and K is the number of hundred kilometres between them.

The isobars on European weather maps commonly indicate pressure differences of 5 millimetres. Hence on these maps the gradient velocity in metres per second is, roughly,

$$60/K$$

On English, Canadian, and American weather maps an isobar is drawn for each tenth of an inch difference in barometric pressure, and in these countries wind velocities are generally expressed in terms of miles per hour. A little calculation, however, adapts the velocity equation to these maps, and shows that for latitude 40° the gradient velocity of the wind is approximately

$$19/M \text{ miles per hour}$$

where M is the number of hundred miles between the adjacent isobars.

These velocities, as already explained, are for latitude 40°, and doubtless therefore are sufficient for most cases, but the following table applies roughly to all regions:

GRADIENT WIND VELOCITY.

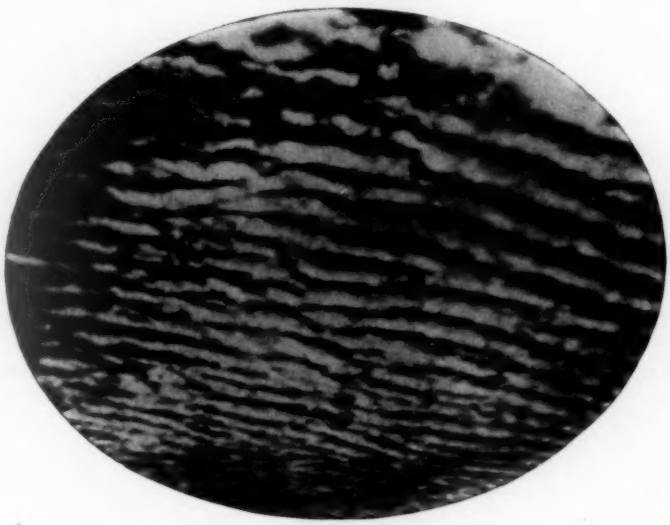
Latitude.	Metres per second.	Miles per hour.
10°	44/K.	70/M.
20°	23/K.	36/M.
30°	15/K.	25/M.
40°	12/K.	19/M.
50°	10/K.	16/M.
60°	9/K.	14/M.
70°	8/K.	13/M.

For regions of higher latitudes than the trade wind belts, gradient velocities generally are reached when the wind is anywhere in the quadrant S.W.–N.W., and not infrequently there is but little change from this velocity through a considerable

range of altitude. On the other hand, when the wind is in the quadrant S.E.–N.E., the full gradient velocity may not obtain at all, and, besides, after reaching a certain altitude the aëronaut may come first into nearly still air, and then into wind of almost any direction and velocity.

This brings us to the consideration of wind layers and their effect on an aëroplane. As first clearly explained by Helmholtz,

FIG. 11.



Clouds; alto-cumulus rolls.

two layers of air that abruptly differ in temperature or humidity, or both, as often happens, can glide the one over the other without rapid intermingling. Any such motion, however, sets up a series of regular interface billows, when the winds are in the same or opposite directions, and irregular, choppy waves when the winds are more or less crossed. Occasionally the cooler crests of aërial billows are rendered conspicuous by long parallel rows of clouds, as shown in Fig. 11, but as such a cloud formation requires a special degree of saturation, it follows that ordinarily, air billows, having nothing to render them visible, must be far more numerous than recorded observations would indicate.

Air sheets of this nature usually occur at altitudes above those

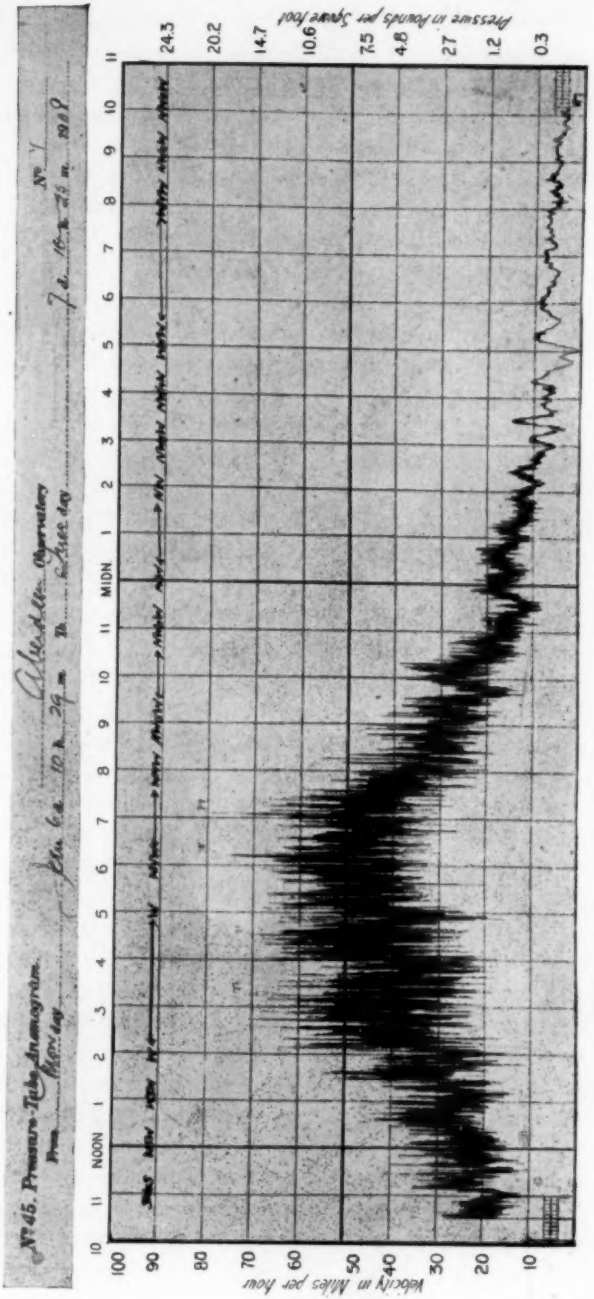
ordinarily frequented by aëronauts, but occasionally they are found well within flying levels, where they may be excessively dangerous. To illustrate, let the aëroplane be headed directly against the wind in an upper current, and let it pass to a lower current moving in the same direction and with the same velocity as the aëroplane. In this case the machine is in precisely the condition of one dropped in still air, and therefore, at least momentarily, is wholly without support or any power of guidance. If this condition should occur at a considerable altitude, a skilful operator, even though volplaning with all power shut off, might still be able to convert his rapid fall into a harmless glide, but his situation certainly would be one of great danger. Nor is the unusual condition here assumed—zero velocity of the machine with reference to the air—the only one that is dangerous. Since, with a given angle of inclination of wing to air,—or, to be technical, a given angle of attack,—the supporting force is approximately proportioned to the square of the velocity, it follows that any decrease in this velocity produces a much greater decrease in the support, and also in the power of control. Besides, wind sheets ordinarily do not flow parallel to each other, either in the same or opposite directions, but more or less across each other, and therefore, as a rule, the aëronaut in going from one such layer to the other has to contend with more than a disconcertingly abrupt change in the supporting force. That is to say, in addition to a partial loss of support, he usually has to contend with the turmoil of a choppy aërial sea, in which his equilibrium is by no means secure. Wind layers of the kind just discussed generally are easily detected by the use of small pilot balloons, and obviously should be carefully avoided by heavier than air machines.

Near the surface of the earth the wind is always in a turmoil, owing to friction and to disturbances caused by hills, bluffs, trees, houses, and numerous other obstacles. Indeed, the actual velocity of the wind at any given place near the earth's surface often varies from second to second by more than half of its average velocity, and the greater the average velocity, the greater, in approximately the same ratio, are the differences in the momentary velocities that rapidly succeed each other.

These facts are well illustrated by pressure tube traces, as shown by Fig. 12, copied from Report No. 9 of the British Advisory Committee for Aëronautics.

Similarly, two places, though separated by no more than fifty

FIG. 12.



Irregularities in the surface wind velocity as indicated by a pressure-tube anemometer.

feet, and that, too, in any direction whatsoever, while having, of course, substantially the same average wind velocities, often have radically different simultaneous velocities. Nor is this all; for near the surface of the earth even the wind direction suffers frequent and erratic momentary changes.

Now it is the momentary condition of the wind, its velocity and direction with reference to each part of his machine, that chiefly concerns the aëronaut; and, as he needs especially steady and uniform conditions, it is quite obvious that the windier it is the higher in general he must fly.

In addition to the horizontal flow of the atmosphere with its incident billows, where one layer glides over another, and surface turmoil, there are also other movements, and especially those due to vertical convection, whether mechanically forced or thermally induced. Thus as examples of the former, when the wind is at right angles in general to the trend of a mountain or range of mountains it is forced to flow up the windward and down the lee side, and the forced billow thus produced so acts upon the higher layers that atmospheric waves parallel to the mountain range extend, though with decreasing amplitudes, to very considerable elevations.

Temperature differences, as above implied, also cause vertical convections that greatly add to the complexity of atmospheric motions, but, fortunately for the aëronaut, the great majority of such movements are too slow seriously to disturb his equilibrium.

Under the influence of insolation, the surface of the earth, especially when it is barren, becomes heated often to many degrees above the average temperature. The soil in turn heats and expands the overlying atmosphere, which is then buoyed up by the adjacent colder and relatively heavy air. In this way currents of air, with an upward velocity sufficient to support soaring birds, are frequently obtained, but ordinarily neither they nor their necessary counterparts, the descending currents, are at all violent. Neither is there any violence in the atmosphere caused by evaporating, and therefore cooling and descending, clouds.

There is, however, a violence of vertical motion and a resulting turbulence in the midst of large cumulus clouds, as their forms and movements plainly show, to which no cautious aëronaut will ever expose himself, even if he should feel lightning proof, which he certainly would not be.

It will be worth while, since it is a mooted question, to consider here the probable cause of the violent motions in large cumulus clouds,—motions of quite a different order of magnitude, presumably, from those of any other portion of the atmosphere, since they are never exhibited by small clouds of any kind, nor met with elsewhere by either manned, sounding or pilot balloons.

Von Bezold [6] shows that sudden condensation from a state of supersaturation, and also sudden congelation following undercooling, would, as a result of the heat thus liberated, cause an equally sudden expansion of the atmosphere, and thereby turbulent motions analogous to those in large cumulus clouds. However, as von Bezold also points out, it is not evident how either the condensation or the freezing could suddenly take place throughout a cloud volume large enough to give the observed effects. Nor does it seem possible, with cloud particles already present, for any appreciable amount of supersaturation to occur. Hence the motions in question presumably have some other cause, and this we shall find in the difference between the actual temperature gradient of the surrounding atmosphere and the adiabatic temperature gradient of the saturated air within the cloud itself.

We will consider a warm summer afternoon, temperature 30° C., say, and assume the dew-point to be 15° C. Now, since the adiabatic decrease of temperature of nonsaturated air is about 1° C. per 100 metres change in elevation, it follows that, under the assumed conditions, vertical convection will cause condensation to begin at an elevation of approximately 1.5 kilometres. From this point, however, assuming the cloud particles to be carried up with the rising air, the rate of temperature decrease becomes much less—drops to about one-half the rate for non-saturated air. After a considerable further rise—half a kilometre, say—the rain drops formed by the additional condensation begin to drop out, and the amount of moisture condensed per degree fall of temperature grows rapidly less, and therefore, for both reasons, the temperature gradient again approaches the adiabatic gradient of dry air, or 1° C. per 100 metres elevation.

Obviously, then, for some distance above the level at which

[6] *Sitzungsberichte Ber. Acad.*, 1892, pp. 279–309. (Translated by Abbe: Mechanics of the Earth's Atmosphere, Smithsonian Institution, 1910, pp. 249–279.)

condensation begins to set free its latent heat, the temperature of the rising mass of moist air departs further and further from the temperature of the surrounding atmosphere at the same level, while the resulting buoyancy correspondingly increases.

In the lower atmosphere gradual and progressive convection prevents the occurrence of any great difference in temperature between the rising column and the adjacent air, and therefore the uprush in this region is never violent. But whenever the vertical movement of the air brings about a considerable condensation, it follows, as above explained, that there is likely to be an increase in the buoyancy, and hence a more or less rapid upward velocity of the central portion, together with a rolling and turbulent motion of the sides of the type so frequently shown by towering cumulus clouds. Obviously, too, the uprushing column of air must ascend more or less beyond its point of equilibrium, and then, because slightly undercooled, correspondingly drop back.

Fig. 13, based upon approximately average conditions, illustrates the points just explained. The elevation is in kilometres, and the temperature in degrees Centigrade.

AB is the approximate temperature gradient for non-saturated air, about 1° C. per 100 metres change in elevation. *GCKDEF* is the supposed temperature gradient before convection begins, or a decrease, in accordance with observations, of 6° C., approximately, per kilometre change of elevation, except near the surface, where the temperature decrease, before convection has begun, ordinarily is less rapid.

As convection sets in, the temperature decrease near the surface approximates the adiabatic gradient for dry air, and this condition extends gradually to greater altitudes till, in the assumed case, condensation begins at the point *C*, or where the temperature is 15° C. Here the temperature decrease, under the assumed conditions, suddenly changes from 10° C. per kilometre to rather less than half that amount, but increases slowly with decrease of temperature. At some point, as *L*, the temperature difference between the rising and the surrounding air is a maximum. At *D* the temperature of the column is the same as that of the surrounding air, but its momentum carries it on to some such higher point as *H*. Within the column, then, the temperature gradient is *ACLDHE*, while the temperature gradient of the surrounding air is given by *ACKDEF*.

The cause, therefore, of the violent uprush and turbulent condition within large cumulus clouds, presumably, is the temperature differences between the interior of the cloud itself and the surrounding atmosphere at the same levels, as indicated by their respective temperature gradients *CLD* and *CKD*.

ELECTRICITY OF THUNDER-STORMS.

The foregoing explanation of the violent uprush in the centre of large cumulus clouds is an important link in the modern theory of the origin of thunder-storm electricity, and therefore suggests that the introduction of that theory at this point would be both logical and in order, especially since it has but recently been developed.

Near the middle of the eighteenth century Franklin showed that the electricity of thunder-storms is an electrical phenomenon, but what its origin is he did not know. Indeed, in spite of numerous attempts to solve this mystery, it was not until quite recently that a consistent and experimentally supported hypothesis in regard to the origin of thunder-storm electricity was developed. The observations that suggested this hypothesis, and the experiments that seem to confirm it, both were made at Simla, India, by Dr. G. C. Simpson,[1] of the Indian Meteorological Department.

By means of a tipping bucket rain-gauge, an automatic record of the rate and time of rainfall was obtained, while at the same time a Benndorf self-registering electrometer marked the sign and potential of the charge acquired during each two-minute interval.

Thousands of such two-minute records were obtained during the monsoon seasons, April 15 to September 15, 1908 and 1909, from which Simpson concludes that:

(1) "The electricity brought down by the rain was sometimes positive and sometimes negative."

(2) "The total quantity of positive electricity brought down by the rain was 3.2 times greater than the total quantity of negative electricity."

(3) "The period during which positively charged rain fell was 2.5 times longer than the period during which negatively charged rain fell."

[1] Part 8, vol. xx, Memoirs of the Indian Meteorological Department.

(4) "Treating charged rain as equivalent to a vertical current of electricity, the current densities were generally smaller than 4×10^{-15} amperes per square centimetre; but on a few occasions greater current densities, both positive and negative, were recorded."

(5) "Negative currents occurred less frequently than positive currents, and the greater the current density the greater the preponderance of the positive currents."

(6) "The charge carried by the rain was generally less than 6 electrostatic units per cubic centimetre of water, but larger charges were occasionally recorded, and in one exceptional storm (13th May, 1908) the negative charge exceeded 19 electrostatic units per cubic centimetre."

(7) "As stated in (3) above positive electricity was recorded more frequently than negative, but the excess was the less marked, the higher the charge on the rain."

(8) "With all rates of rainfall positively charged rain occurred more frequently than negatively charged rain, and the relative frequency of positively charged rain increased rapidly with increased rate of rainfall. With rainfall of less than about 1 millimetre in two minutes, positively charged rain occurred twice as often as negatively charged rain, while with greater intensities it occurred fourteen times as often."

(9) "When the rain was falling at a less rate than about .6 millimetre in two minutes, the charge per cubic centimetre of water decreased as the intensity of the rain increased."

(10) "With rainfall of greater intensity than about .6 millimetre in two minutes the positive charge carried per cubic centimetre of water was independent of the rate of rainfall; while the negative charge carried decreased as the rate of rainfall increased."

(11) "During periods of rainfall the potential gradient was more often negative than positive, but there were no clear indications of a relationship between the sign of the charge on the rain and the sign of the potential gradient."

(12) "The data do not suggest that negative electricity occurs more frequently during any particular period of storm than during any other."

Since the publication of Simpson's work, similar observations have been made at a number of other places, notably in France and Germany, and in all cases the results were in substantial

agreement with those obtained in India, so that there can no longer be any doubt of the universality of the phenomena in question.

Simpson also devised a number of laboratory experiments imitative of thunder-storm conditions, and noted the electrical effects thus produced. Freezing, thawing, air friction and a few other things all gave negative results. Finally the breaking up of drops of distilled water by an air blast was tried, and at once positive results were obtained, showing that:

(1) "Breaking of drops of water is accompanied by the production of both positive and negative ions."

(2) "Three times as many negative ions as positive ions are released."

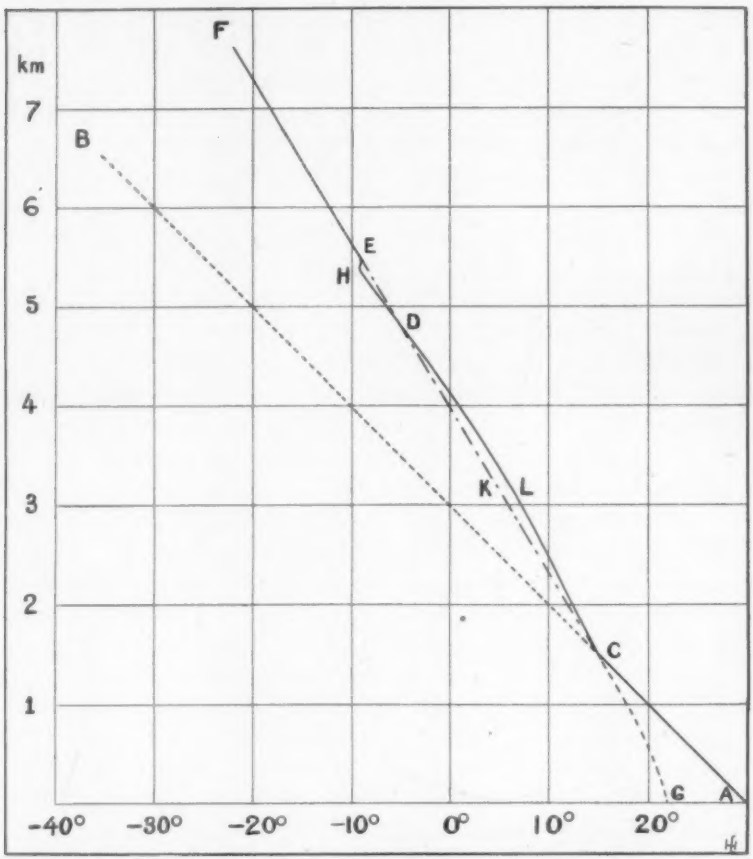
Now, as thunder-storms are usually, if not always, connected with large cumulus clouds, it follows, as explained in connection with Fig. 13, that a vigorous uprush of air is a necessary accompaniment of thunder-storms. Further, if the upward velocity of the air is as much as 8 metres per second—and it may easily exceed this amount—then no water drops, whatever their size, can fall through it. Those already small enough will be carried up, while the larger drops will be torn to bits, and the spray thus formed carried aloft.

It appears, then, that the strong upward currents of air within cumulus clouds necessarily must break up and thereby positively electrify the larger rain drops. These in turn doubtless unite again, possibly many times, only to be rebroken and still further positively charged. After a time the drops, of course, reach a place where the uprush of air is not sufficient to support them, and they fall as positively charged rain, while the negatively charged spray is blown aloft, from whence, after more or less coalescence into larger drops, it falls as negatively charged rain; though much of the negatively charged spray necessarily remains aloft, where it is slowly evaporated. Hence the bulk of the electricity brought down is positive, and hence, too, the heavier portions of the rain and the larger drops usually are positively charged, while the negative electricity is mainly confined to the lighter part of the storm, when the drops, as a rule, are comparatively small.

This, then, is the latest and apparently correct idea, as developed by Simpson, of the origin of the great amount of electricity in thunder-storms. If it had a weak point at all, as first

set forth, it was in the assumption that such storms are always accompanied by a rapid uprush of air, sufficient to split up the larger rain drops; but Fig. 13 and its discussion seem to justify the assumption and thus fully to strengthen the one weak link in the logical chain.

FIG. 13.



Temperature gradients within and without cumulus clouds.

The above discussions might be greatly extended, and additional topics added to an almost indefinite extent, but this is impracticable, and, besides, it is hoped that enough has already been said to illustrate the claim made at the outset, to the effect that meteorology really is a branch of applied physics, full of the most interesting physical problems, both solved and unsolved.

THE BEHAVIOR OF ACID AMIDES IN THE SOIL.[1]

BY

SAMUEL L. JODIDI, B.S., Ph.D.

(CONTRIBUTION FROM THE CHEMICAL RESEARCH LABORATORY, SOILS SECTION, IOWA STATE COLLEGE AGRICULTURAL EXPERIMENT STATION.)

Of the well-known ten elements which have been recognized as essential for plant life, nitrogen plays a very prominent rôle. However, from the standpoint of plant food it is the available nitrogen—ammonia and nitrates—which is of special importance. Inasmuch as the nitrites and nitrates present in soils are chiefly the result of the nitrification of ammonia, it is at once evident that investigations concerning the formation of ammonia in soils will necessarily shed light upon the question of available nitrogen as a whole. Again, the production of ammonia in soils is closely associated with the chemical nature of the organic nitrogenous compounds occurring in soils.

Since it was shown by the writer [2] that acid extracts of soils are made up principally of monoamino acids, diamino acids, and ammonia—which latter is the result of the hydrolysis of acid amides contained in the protein molecule—it seems of considerable interest experimentally to demonstrate the behavior of the above compounds in the soil. Some of the changes to which amino acids are subjected in soils were reported in a previous publication. The latter contains, among other data, the results of ammonification of pure amino-acids like glycocoll, alanine, leucine, tyrosine, etc., on the one hand, as well as of asparagine—which is simultaneously an amino acid and acid amide—on the other. In this article the results of ammonification of acetamide and propionamide are presented.

The ammonia which is found on hydrolysis of proteins is commonly due to the presence in their molecule of the dicarboxylic acids asparagine and glutamine, which are contained in

[1] Communicated by the author.

[2] *Journ. Amer. Chem. Society*, vol. 32, 396 (1910); vol. 33, 1226 (1911); vol. 34, 94 (1912).

the protein molecule in the form of acid amide radicals. However, the behavior in the soil of acid amides other than those contained in the protein molecule is also of interest not only scientifically but for practical considerations as well. Aside from the fact that acid amides come into the soil with manures, it should be remembered that compound esters of organic acids not infrequently occur in nature,—for instance, in ethereous oils, wachses, fats, etc. Bearing in mind that esters easily combine with ammonia to form acid amides, it was deemed advisable to observe the behavior in the soil of acetamide and propionamide.

As is well known, the acid amides materially differ from amino-acids in their chemical behavior, which is due to their different chemical constitution: while in the former the NH_2 group is linked with the carbonyl group, it is in the latter directly united with the alkyl. In conformity with this different structure, the NH_2 group in the acid amides can be split off by various chemical means,—for instance, by treatment with boiling acid or with superheated steam,—whereas these means do not affect the amino-acids. However, our observations made with amino-acids and acid amides go to show that their behavior in the soil is not materially different, so far as ammonification is concerned. The above facts indicate that the deamination in the soil is due not to chemical processes but rather to bacterial activities.

Since factors like moisture, temperature, air, etc., have great influence on decomposition of organic matter, it was thought necessary to carry out the experiments under uniform conditions which fairly closely approach those existing in the soil, in order to be justified to draw more general conclusions from the comparable results thus secured. Accordingly, we kept the soils treated with acid amides always at room temperature; the moisture of the soils was throughout the experiments uniform, namely, about eighteen per cent.; the soils were always placed in covered tumblers or in beakers covered with Petri plates, in each case allowing sufficient circulation of air for maximal activity of the micro-organisms in question.

For the experiments reported in this investigation we used a soil composed of samples taken from twenty-two plots of the Iowa Agricultural Experiment Station field, which is situated on the Wisconsin drift. The soils in question were secured from the above plots in the fall of 1911. The plots having the size of

one-tenth or one-twentieth of an acre were treated with various organic materials, such as manure, timothy, clover, peat, and grew a variety of crops, namely: corn, oats, timothy, clover, and cowpeas. The exact treatment of the plots, as well as their cropping up to 1909 inclusive, is recorded in form of a table in a former publication.[3]

The average composition of the composite soil used for the ammonification experiments was as follows:

Moisture	18.68	per cent.
Total nitrogen	0.296	per cent.
Ammoniacal nitrogen	1.63	per cent.
Nitric nitrogen	2.66	per cent.

The latter two figures are expressed in percentage of the total soil nitrogen. In connection with the ammonia determinations a few remarks may not be out of place here, bearing in mind that this paper is mainly based upon the ammonification experiments, and, further, that soils ordinarily contain but small amounts of ammonia, as was shown by our previous investigations,[4] as well as by those of others. For this reason it is quite essential to have an exact method for estimation of ammonia present or produced in soils. Especially was it deemed advisable to compare the mode of direct distillation of soils with magnesium oxide, which is most commonly in use, with the results obtainable according to Schlösing's method. The latter consists, as is known, in that to the soil mixed with double the amount of distilled water strong hydrochloric acid is added to distinctly acid reaction, whereupon more water is added to make up the liquid to a definite volume, which is commonly four times the amount of soil used. The whole is then well shaken, allowed to stand for several hours, whereupon an aliquot part of the filtrate is distilled with sodium hydroxide solution. The direct distillation of the soils with magnesium oxide was carried out in the usual way. In each case 50 grammes of soil were, with the aid of 100 or 150 c.c. of distilled water, quantitatively transferred to a copper flask of 600 or 1000 c.c. capacity, to which there were added some paraffin and about ten grammes of magnesium oxide

[3] Jodidi and Wells, Iowa Agr. Exp. Sta. Research Bull. No. 3, pp. 123, 124.

[4] Jodidi, S. L., *Journ. Amer. Chem. Soc.*, vol. 32, 405 (1910); vol. 33, 1230 (1911); vol. 34, 95 (1912).

previously reduced to cream with 100 c.c. of distilled water. The flask was now heated, the distillate being received in an Erlenmeyer flask containing $\frac{n}{10}$ H_2SO_4. The titration was performed against standard sodium hydroxide solution. The results obtained according to Schlösing's method are recorded in Table I, those secured by direct distillation of the soils with magnesium oxide are given in Table II.

TABLE I.

Plots of 1911.	Wet soil used, grammes.	Corresponding oven-dried soil, grammes.	Nitrogen found.		
			Gramme.	Per cent. of oven-dried soil.	Per cent. of total soil nitrogen.
A.....	100	84.25	0.00083	0.0010	0.273
B.....	100	76.58	0.00091	0.0012	0.287
C.....	100	77.20	0.00091	0.0012	0.309
D.....	100	90.85	0.00176	0.0019	0.577
E.....	100	76.60	0.00111	0.0014	0.541
F.....	100	77.86	0.00225	0.0029	0.976
G.....	100	79.50	0.00142	0.0018	0.643
H.....	100	80.04	0.00101	0.0013	0.530
I.....	100	81.09	0.00232	0.0029	1.085
J.....	100	81.43	0.00204	0.0025	1.053
K.....	100	80.95	0.00107	0.0013	0.580
L.....	100	80.58	0.00102	0.0013	0.465
M.....	100	79.46	0.00119	0.0015	.....
N.....	100	79.33	0.00204	0.0026	0.887
O.....	100	84.79	0.00129	0.0015	0.474
P.....	100	84.11	0.00119	0.0014	0.427
Q.....	100	81.77	0.00041	0.0005	0.156
R.....	100	83.12	0.00111	0.0013	0.429
S.....	100	84.20	0.00101	0.0012	0.467
T.....	100	81.72	0.00260	0.0032	1.354
U.....	100	81.76	0.00101	0.0012	.....
V.....	100	81.84	0.00055	0.0007	0.242

In glancing over the Tables I and II we note that Schlösing's method gave considerably smaller figures, in the case of all the soils examined. This fact must be attributed to the presence in the soils of organic nitrogenous compounds which on direct distillation with magnesium oxide split off a part of their nitrogen in form of ammonia. Those compounds are, at least in part, of the acid amide and amino-acid type, as will be shown later.

In this paper, however, we decided to use the mode of direct distillation of the soils with magnesium oxide, because it is more convenient and requires less time. In addition, it should be

borne in mind that by running blank analyses the above-mentioned error was eliminated as much as possible.

In connection with Table I mention may be made here of the fact that the data in question were secured by leaving the soils in contact with water and hydrochloric acid for a few hours

TABLE II.

Plots of 1911	Wet soil used, grammes.	Corresponding oven-dried soil, grammes.	Nitrogen found.		
			Gramme	Per cent. of oven-dried soil.	Per cent. of total soil nitrogen.
A.....	50	42.13	0.00142	0.0034	0.94
B.....	50	38.29	0.00131	0.0034	0.83
C.....	50	38.60	0.00212	0.0055	1.44
D.....	50	45.43	0.00153	0.0034	1.00
E.....	50	38.30	0.00159	0.0042	1.55
F.....	50	38.93	0.00212	0.0054	1.84
G.....	50	39.75	0.00212	0.0053	1.92
H.....	50	40.02	0.00212	0.0053	2.23
I.....	50	40.55	0.00170	0.0042	1.59
J.....	50	40.72	0.00208	0.0051	2.15
L.....	50	40.29	0.00205	0.0051	1.87
M.....	50	39.73	0.00191	0.0048	1.40
N.....	50	39.67	0.00184	0.0046	1.72
P.....	50	42.06	0.00254	0.0060	1.82
Q.....	50	40.89	0.00166	0.0041	1.26
R.....	50	41.56	0.00240	0.0058	1.86
S.....	50	42.10	0.00222	0.0053	2.05
T.....	50	40.86	0.00212	0.0052	2.21
U.....	50	40.88	0.00212	0.0052	1.63
V.....	50	40.92	0.00142	0.0035	1.25

only—anyway, not more than over night. When, however, the soils K, L, M, N, and O were treated with hydrochloric acid (10 c.c.) and distilled water (the total amount of liquid being 400 c.c.) and left in contact with the liquid for four days, the amounts of ammonia nitrogen found on distillation were as follows:

Plots of 1911.	Wet soil used, grammes.	Corresponding oven-dried soil, grammes.	Ammonia nitrogen found.		
			Gramme.	Per cent. of oven-dried soil.	Per cent. of total soil, nitrogen.
K.....	100	80.95	0.00354	0.0044	1.918
L.....	100	80.58	0.00288	0.0036	1.314
M.....	100	79.46	0.00298	0.0038	.....
N.....	100	79.33	0.00438	0.0055	1.904
O.....	100	84.79	0.00489	0.0058	1.797

When we compare these figures with the results as summarized in Table I we can readily see that the percentage of ammonia found in the same soils increased as a consequence of the longer period during which they were in contact with the dilute hydrochloric acid. Inasmuch as the quantitative extraction of ammonia present as such in soils can be accomplished in a few hours, the only logical interpretation is the assumption that the soils examined contain nitrogenous compounds of the acid amide type which, subjected to the action of dilute hydrochloric acid, split off their nitrogen in the form of ammonia.

For the ammonification experiments with the acid amides it was deemed necessary to use a homogeneous, composite soil rather than the individual soils. The employment of the individual soils —which differ from each other so far as the percentages of moisture, total nitrogen, ammonia, nitric and organic nitrogen are concerned—would involve a considerable number of conditions rendering the experiments complicated and their interpretation difficult. Hence, the soils of the twenty-two plots were mixed as thoroughly as possible. We preferred to apply the field-wet soils instead of the air-dried ones, although it is quite hard, if at all possible, to obtain very good average samples of wet soils. This was done for the reason that soils, after they have been air-dried and then treated with water to make up their original moisture content, no longer possess the properties which the field-wet soils had, so far as, for instance, the biological processes of ammonification and nitrification are concerned.

SERIES I.

AMMONIFICATION OF ACETAMIDE IN THE SOIL.

The acetamide which was used for the following experiments was on purification subjected to analysis by the Kjeldahl method, which gave 23.62 per cent. nitrogen, while the formula CH_3CONH_2 requires 23.76 per cent. nitrogen.

Various amounts of acetamide were thoroughly mixed with weighed amounts of soil and kept in beakers covered with Petri dish covers at room temperature which ranged from 20° to 31° C. The odd soil numbers were distilled with magnesium

oxide, the even numbers (their duplicates) with barium carbonate. The different reagents were used because it was found that acetamide, when mixed with soil and subjected without delay to distillation with magnesium oxide, split off a portion of its nitrogen in the form of ammonia. This is also true of propionamide. The amount of ammonia obtained by immediate distillation of acetamide and propionamide (plus soil), with either magnesium oxide or barium carbonate, was subtracted from the quantity of ammonia found on distillation of the acid amide-treated soils after they had undergone the process of ammonification.

That ammonia can fairly quantitatively be driven off by distillation of ammonia containing substances with barium carbonate, just as it can be done by distillation with magnesium oxide or sodium hydroxide, is evident from the following experiment: One gramme of ammonium chloride and ammonium sulphate respectively was dissolved in water, made up to 1000 c.c. and mixed well. Of these solutions 100 c.c. portions were distilled with either sodium hydroxide, magnesium oxide, or barium carbonate. The nitrogen obtained by distillation with magnesium oxide and barium carbonate was calculated to the nitrogen found by distillation with sodium hydroxide, the latter having been put down as 100 per cent. The data obtained are given in the following tabulation:

Substance applied.	Of solution taken, c.c.	$^{n}/_{10}H_2SO_4$ used, c.c.	Nitrogen found.	
			Gramme.	Per cent.
Ammonium chloride.	100	18.07	0.02537	100.00
Ammonium chloride.	100	18.10	0.02541	100.16
Ammonium chloride.	100	17.72	0.02487	98.03
Ammonium sulphate	100	14.77	0.02074	100.00
Ammonium sulphate	100	14.53	0.02040	98.36
Ammonium sulphate	100	14.20	0.01994	96.14

The results of the ammonification are presented in the following tables:

Soil number.	Amount of soil used for ammonification, grammes.	Moisture found.		Amount of substance added.
		Per cent.	Average.	
1	25	18.30		0.1 gr. acetamide
2	25	18.53	18.42	0.1 " "
3	50	18.48		0.1 " "
4	50	18.24	18.36	0.1 " "
5	100	18.40		0.1 " "
6	100	18.47	18.44	0.1 " "
7	150	18.32		0.1 " "
8	150	18.31	18.32	0.1 " "
9	25	18.51		0.2 " "
10	25	18.37	18.44	0.2 " "
11	50	18.41		0.2 " "
12	50	18.22	18.32	0.2 " "
13	100	18.42		0.2 " "
14	100	18.24	18.33	0.2 " "
15	150	18.37		0.2 " "
16	150	17.75	18.06	0.2 " "
17	25	18.14		0.3 " "
18	25	18.59	18.37	0.3 " "
19	50	18.42		0.3 " "
20	50	18.63	18.53	0.3 " "
21	100	18.55		0.3 " "
22	100	18.41	18.48	0.3 " "
23	150	18.32		0.3 " "
24	150	18.37	18.35	0.3 " "
25	25	18.26		0.5 " "
26	25	18.27	18.27	0.5 " "
27	50	18.47		0.5 " "
28	50	18.53	18.50	0.5 " "
29	100	18.36		0.5 " "
30	100	18.36	18.36	0.5 " "
31	150	18.25		0.5 " "
32	150	18.44	18.35	0.5 " "
33	25	18.01		1.0 " "
34	25	18.00	18.01	1.0 " "
35	50	18.01		1.0 " "
36	50	18.02	18.02	1.0 " "
37	100	18.22		1.0 " "
38	100	18.27	18.25	1.0 " "
39	150	18.06		1.0 " "
40	150	18.32	18.19	1.0 " "
41	25	18.42		2.0 " "
42	25	18.52	18.47	2.0 " "
43	50	18.26		2.0 " "
44	50	18.03	18.15	2.0 " "
45	100	18.11		2.0 " "
46	100	18.04	18.08	2.0 " "
47	150	18.44		2.0 " "
48	150	18.76	18.60	2.0 " "

Soil number.	Duration of ammonification.	Ammonia nitrogen found.		
		Milligrammes.	Average.	Per cent. of total nitrogen.
1	Nine days	18.81		
2	" "	18.79	18.80	79.59
3	" "	20.01		
4	" "	17.76	18.89	79.97
5	" "	17.95		
6	" "	14.63	16.29	68.97
7	" "	15.17		
8	" "	11.71	13.44	56.90
9	" "	31.67		
10	" "	35.48	33.58	71.08
11	" "	39.88		
12	" "	38.93	39.41	83.43
13	" "	37.49		
14	" "	32.66	35.08	74.26
15	" "	35.24		
16	" "	.....	35.24	74.60
17	Ten days	50.82		
18	" "	49.63	50.23	70.89
19	" "	58.64		
20	" "	58.29	58.47	82.51
21	" "	56.93		
22	" "	51.58	54.26	76.57
23	" "	52.83		
24	" "	.....	52.83	74.56
25	Twelve days	9.48		
26	" "	9.62	9.55	8.09
27	" "	86.35		
28	" "	90.39	88.37	74.83
29	" "	94.25		
30	" "	88.69	91.47	77.45
31	" "	90.44		
32	" "	.....	90.44	76.58
33	" "	12.99		
34	" "	7.93	10.46	4.43
35	" "	17.90		
36	" "	14.60	16.25	6.88
37	" "	190.15		
38	" "	175.78	182.97	77.46
39	" "	195.14		
40	" "	170.38	182.76	77.38
41	Thirteen days	5.04		
42	" "	5.38	5.21	1.10
43	" "	15.36		
44	" "	13.13	14.25	3.02
45	" "	16.16		
46	" "	.....	16.16	3.42
47	" "	211.20		
48	" "	217.55	214.38	45.38

From the data just given we note that the agreement in the moisture content of the soil portions and their duplicates is very satisfactory. We further note that in the first 24 soils the production of ammonia is practically proportional to the quantity of acetamide added. However, in looking over the results in connection with the soils 25–48 we find some very striking figures. When the distillates obtained from the soil portions 25 and 26 were titrated and unusually small amounts of ammonia were found, it was first thought that loss in the operations must have occurred. The further titrations, however, have shown that what was true of the soils 25 and 26 held also good for the soil portions 33–36 and 41–46, in all of which the production of ammonia was materially reduced. In fact, in some cases it practically stopped altogether. A closer examination of the soils in question shows that the noticed phenomenon was the case when relatively large amounts of acetamide were added to comparatively small quantities of soil. Now, in the light of modern researches, decomposition of organic matter, like the process of ammonification, for instance, is the result of the activities of certain bacteria. Those activities can essentially be influenced by the presence of chemical substances. Thus, the bacteria can best thrive in a slightly alkaline medium. The presence of alkalies, acids, or soluble salts in excess reduces or stops bacterial activities altogether. In the particular case of ammonification the presence of ammonium salts in excess has the same effect. From the experiments of the acetamide series it follows that the presence of acid amides, like acetamide—and propionamide, as will be shown in the next series—influences the life functions of the bacteria in the same sense as do the acids, alkalies, or salts. So long as the quantity of acetamide added to the soil was in certain limits, the acetamide ammonified quite vigorously. When, however, the ratio of acetamide to soil increased, the ammonification of acetamide showed the tendency toward decreasing, and practically stopped altogether beyond a certain limit. The above facts can best be comprehended when we take into consideration the chemical nature of acid amides. They are neutral compounds and show neither basic nor acid properties, since the nature of the ammonia is neutralized by the acid residue. In other words, the acid amides can in a certain sense be considered as intra-

molecular salts, made up of an organic acid, on the one hand, and of ammonia, on the other. Hence, what is true of salts must also hold good for acid amides. When present in considerable quantities in the soil they must depress, or even stop, the activities of bacteria-producing ammonia. This, by the way, points to the necessity of distributing manures and commercial fertilizers in the soil as uniformly as possible.

Another interesting fact is that acid amides not occurring in the protein molecule, such as acetamide, ammonify in the soil as readily as asparagine, which is found in most of the proteins. Or, to put it in other words, the bacteria which are instrumental in bringing about the process of ammonification can utilize for their life functions acid amides not contained in the protein molecule, just as they are able to use the proteins themselves or those products of which the protein bodies are made up.

SERIES II.

AMMONIFICATION OF PROPIONAMIDE IN THE SOIL.

For the present series propionamide was used which on purification analyzed 19.00 per cent. nitrogen, as against 19.20 per cent. required by the formula $CH_3.CH_2.CO.NH_2$.

Fifty, seventy-five, one hundred, and one hundred and twenty-five gramme portions of soil were weighed out into tumblers and well mixed with various amounts of propionamide. The mixtures were kept in the covered tumblers at room temperature. The lowest temperature observed was 20° C., the highest 28°. The odd soil portions were distilled with magnesium oxide, their duplicates (the even numbers) with barium carbonate.

The results obtained are presented in the tables on the following pages.

While the agreement in the soil portions and their duplicates as to their moisture content is altogether satisfactory, the figures representing the amounts of ammonia produced are in some instances quite striking. We note that in the first 24 soil portions, with the exception of numbers 17 and 18, the intensity of ammonification was considerable. On the whole, the quantity of ammonia formed was here proportional to the quantity of pro-

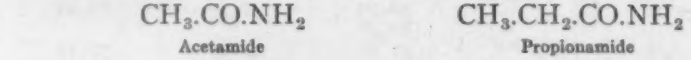
Soil number.	Amount of soil used for ammonification, grammes	Moisture found.		Amount of substance added.
		Per cent	Average.	
1	50	18.29		0.1 gram propionamide
2	50	18.09	18.19	0.1 " "
3	75	18.22		0.1 " "
4	75	18.26	18.24	0.1 " "
5	100	18.40		0.1 " "
6	100	18.37	18.39	0.1 " "
7	125	18.19		0.1 " "
8	125	18.45	18.32	0.1 " "
9	50	18.50		0.2 " "
10	50	18.00	18.25	0.2 " "
11	75	18.74		0.2 " "
12	75	18.11	18.43	0.2 " "
13	100	18.80		0.2 " "
14	100	18.47	18.64	0.2 " "
15	125	18.26		0.2 " "
16	125	18.06	18.16	0.2 " "
17	50	19.03		0.3 " "
18	50	19.13	19.08	0.3 " "
19	75	18.14		0.3 " "
20	75	18.55	18.35	0.3 " "
21	100	18.85		0.3 " "
22	100	18.73	18.79	0.3 " "
23	125	18.41		0.3 " "
24	125	18.41	18.41	0.3 " "
25	50	18.77		0.5 " "
26	50	18.66	18.72	0.5 " "
27	75	18.46		0.5 " "
28	75	18.48	18.47	0.5 " "
29	100	18.44		0.5 " "
30	100	18.11	18.28	0.5 " "
31	125	18.71		0.5 " "
32	125	18.59	18.65	0.5 " "
33	50	18.30		0.75 " "
34	50	18.30	18.30	0.75 " "
35	75	18.74		0.75 " "
36	75	18.56	18.65	0.75 " "
37	100	18.24		0.75 " "
38	100	18.36	18.30	0.75 " "
39	125	18.34		0.75 " "
40	125	18.17	18.26	0.75 " "
41	50	18.46		1.0 " "
42	50	18.58	18.52	1.0 " "
43	75	18.56		1.0 " "
44	75	18.51	18.54	1.0 " "
45	100	18.77		1.0 " "
46	100	18.15	18.46	1.0 " "
47	125	18.38		1.0 " "
48	125	18.76	18.57	1.0 " "

pionamide added to the soil. However, an examination of the the soil portions 25–48 shows that the intensity of ammonification was here very much depressed. When we consider the figures

Soil number.	Duration of Ammonification.	Ammonia nitrogen found.		
		Milligrammes.	Average.	Per cent. of total nitrogen.
1	Eight days	13.44		
2	" "	14.17	13.81	72.68
3	" "	13.18		
4	" "	12.75	12.97	68.26
5	" "	13.09		
6	" "	11.78	12.44	65.47
7	" "	12.07		
8	" "	.....	12.07	63.53
9	" "	28.68		
10	" "	28.15	28.42	74.79
11	" "	28.61		
12	" "	28.33	28.47	74.92
13	" "	26.01		
14	" "	26.79	26.40	69.47
15	" "	26.53		
16	" "	26.30	26.42	69.53
17	Ten days	14.21		
18	" "	14.75	14.48	25.40
19	" "	42.68		
20	" "	42.97	42.83	75.14
21	" "	42.75		
22	" "	40.79	41.77	73.28
23	" "	40.46		
24	" "	39.53	40.00	70.18
25	" "	13.91		
26	" "	14.86	14.39	15.15
27	" "	20.68		
28	" "	20.26	20.47	21.55
29	" "	53.49		
30	" "	43.29	48.39	50.94
31	" "	71.19		
32	" "	68.07	69.63	73.29
33	" "	23.14		
34	" "	15.70	19.42	13.63
35	" "	26.54		
36	" "	22.02	24.28	17.04
37	" "	33.35		
38	" "	28.47	30.91	21.69
39	" "	45.07		
40	" "	33.42	39.25	27.54
41	Eleven days	19.07		
42	" "	14.64	16.86	8.87
43	" "	28.01		
44	" "	23.03	25.52	13.43
45	" "	32.23		
46	" "	28.71	30.47	16.04
47	" "	38.33		
48	" "	43.71	41.02	21.59

more closely we find that the depression of ammonification is congruent with the increase of the ratio of propionamide to soil. In other words, here, as in the case of acetamide, the intensity of ammonification reaches its maximum within certain

limits beyond which it shows the tendency rapidly to decrease. The explanation for this phenomenon is again to be found in the chemical nature of propionamide, which represents, so to speak, an intramolecular salt. The latter, being easily soluble in water, forms in the soil a concentrated solution which depresses the activities of the ammonia-producing bacteria. On the other hand, this series confirms the data recorded in Series I, inasmuch as both propionamide and acetamide, not known to occur in the protein molecule, ammonify in the soil as readily as does asparagine, which has been found in most of the proteins investigated. It also confirms the observation already reported by the writer in another paper,[5] so far as the influence of the chemical constitution of a body on the intensity of its ammonification is concerned. Accordingly, propionamide approaches, although it does not fully reach, the acetamide in the intensity of ammonification, in agreement with the fact that propionamide is the next higher homologue of the acetamide, as illustrated by the following formulas:



$CH_3.CO.NH_2$ — Acetamide

$CH_3.CH_2.CO.NH_2$ — Propionamide

The above fact may, perhaps, be applicable in a more general way. In case of doubt as to the chemical constitution of a substance, its behavior in the soil, and especially the intensity of its ammonification, may give data throwing light upon the structure of its molecule.

The data secured permit of drawing the following conclusions:

Acetamide and propionamide readily undergo in the soil the process of ammonification.

As in the case of amino-acids,[6] the rate of transformation of the acid amide nitrogen into ammonia is greatly influenced by their chemical structure, so that acid amides of equal structure yield about the same proportion of ammonia.

The maximum percentages of ammoniacal nitrogen obtained from acetamide and propionamide were 83.43 and 75.14 respectively.

My thanks are due to Mr. E. H. Kellogg and R. Snyder for assistance in carrying out the routine work.

[5] *Loc. cit.* [6] *Loc. cit.*

THE ENGINEER IN THE BUILDING OF THE REPUBLIC.*

BY

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WHO is he? What manner of man is this who has had a hand in the building of the Republic, and what has he done?

Who is he? Why, he is a man, every inch of him, a man to be reckoned with.

What manner of man is he? Physically, like King Saul of old, he may stand head and shoulders above the people; he may be a man of brawn and sinew or he may be frail and dapper, but in either case he will have the gift of continuance; he will set out to reach a goal, and, no matter what obstacles lie in his path, he will reach it.

He endures hardship like a good soldier; summer's heat and winter's cold try his endurance, but he endures. He traverses the rough places of the earth with an assured tread; his path is in the wilderness, and the solitary places know his footfall. If hunger overtakes him, he tightens his belt and still endures; thirst parches his tongue, but there are water springs, and he endures until their cooling draughts refresh him. The physical man is dominated by the intellectuality which dwells within him. Engineering is a science far-reaching and many-sided, dealing with the forces of Nature in all of their varied forms and combinations. This man of whom we are talking, perhaps—we may say assuredly—has not mastered this science in all of its branches, but he has chosen the division of that science to which he will devote his energies, physical and mental, and *that* he knows. He may have acquired that knowledge within college walls, and his alma mater may be dear to him, or he may have acquired what he knows in the hard school of experience, ending up days of toil with nights of study that he may know the reason for the things he has been doing or be ready to meet the problems that

* Presented at the stated meeting of the Institute held Wednesday, December 18, 1912.

he knows lie ahead of him. He has more or less of the constructive instinct. He is a dreamer who can shut his eyes and see the thing he means to create take outline and form upon the trestle-board of his imagination. Or he maps in relief the territory over which he has tramped and selects upon the wrinkled face of Nature those furrows through which he will carry his roadway, excavate his canal, or across which he will build his dam.

We have looked him over physically and mentally, but we cannot pass on to his work without a glance at his moral equipment. Honor lies at the base of the character of the engineer worthy of the name, and an honesty which is proof against the wiles of the devil or of fellow-man. We have now had an introduction to the man who has been doing things for the Republic. Let us see what he has been doing.

Less than a month ago I loitered beside a small land-locked harbor in one of our Chicago parks, and in that safe refuge there were three tiny ships of quaint design. It was a gala day, and these ships were bright with fluttering multi-colored flags, but dominating all was the flag that carries forty-eight stars upon a field of blue, from which thirteen united stripes swelled out upon the gentle breeze. Those ships had names that carried memory back over 420 years of American history, the *Pinta,* the *Nina,* and the *Santa Maria,* replicas of the three tiny craft that brought the first adventurous explorers from Spain to the New World; men whose courage and whose faith canonize them among the immortals. They found a wilderness world where the savage waged a never-ending strife with the wild beast. Years rolled by, and the men of England and the men of France followed in the wake of the men of Spain and laid claim to the new land, and the land and the savage and the wild beasts fought against the invaders. For a time inhospitable shores and savages and wild beasts prevailed against the white skins from over the sea, but the avarice of the white man with such a prize in view proved indomitable, and the lodgments along the St. Lawrence, the north Atlantic coast, the bays of Virginia, the coast of the Carolinas, Georgia, and Florida, and on the Mississippi were abiding, and the fate of the red man was irrevocably settled. He was to be despoiled of his lands; his hunting grounds were to become the arable lands of the whites; his herds of bison

were to be slaughtered for the value of their pelts or even for the wanton sport of the whites; his tribes must retire as civilization advanced, and at last, hemmed in between this advance from both coasts, "'minished and brought low," their remnants were to become the wards and the pensioners of the all-conquering whites. But this was the outcome of long years of struggle, not the result of sudden and decisive combat.

In this new land the waterways were the highways, for the forests were trackless, the streams unbridged, and the prairies were like uncharted seas. The settlements were along the bays and rivers, and there the cities grew. I was once a guest at a Washington Birthday dinner. One of the speakers was a railroad magnate to whom the topic assigned was "The Transportation Facilities of 1776." He arose and announced his topic and said, "It is one easily disposed of, there were none," but, nevertheless, he gave a very interesting talk upon this topic. But it is about time to make some showing for the engineer. May we not claim as one of us the man who began his career as a surveyor, locating by metes and bounds the princely estate of Thomas (Lord) Fairfax, the man who served with Braddock and saved the remnant of that ill-fated commander's army, the man who was the forefront and tower of strength of the American Revolution which made him the Father of his Country? The "Father of his Country," having fought for its liberties and won them, had all of a father's care for the nation that was born to him. None knew better than he the vastness and the inherent wealth of the land which they possessed, and none knew better than he what was needed to make that land what he saw it in his visions of the future. He recognized transportation as the foremost factor in the development of the new land. He planned highways and canals to meet the needs of transportation. The first canal project in the new land, of which history tells us, was the James River and Kanawha Canal, the first conception of which dates back to 1716 and is accredited to Governor Spotswood. But the first active steps directed to the realization of this project were taken by Washington, "who saw from his backwoods days the necessity of joining the eastern seaboard to the trans-Alleghanian territory by lines of communication." "He personally explored the James River route in 1784, and induced the Legislature of Virginia, on the 5th of January, 1785,

to pass an act for the improvement of the James." Under this act the James River Company was organized on the 25th of January, 1785, with Washington as president. But time went by and Washington had rested for long years in his sarcophagus at Mount Vernon before a boat passed through that canal. His name is more intimately connected with the Chesapeake and Ohio Canal, which, as designed by him, was to connect the Chesapeake and ocean navigation by way of the Potomac with that of the Ohio by portages and high roads from Cumberland, at the foot of the Alleghanies. The route chosen by him from the head of navigation on the Potomac at or near Georgetown as far as Harper's Ferry was on the Virginia side of the river; after an expenditure of about three-quarters of a million dollars, this location was abandoned and the canal was built on the Maryland side, and it is one of the few early canals still in operation.

In 1790, Washington, as the head of a commission of three, acting under authority of Congress, selected the site of the capital of the young nation. *He* called it the Federal City. "Major l'Enfant, a French engineer serving in the Continental Army, was employed to superintend the laying out of the city, following plans outlined by Washington, derived, it is believed, from the outlines of Versailles, France." We cannot escape from the belief that Washington, born soldier, was also a born engineer. Canals and highways called forth the first efforts of the engineers of the new land. Their most conspicuous work was and is the Erie Canal, connecting Lake Erie with the Hudson River. Ground was broken for this canal July 4, 1817, and the original project was completed October 25, 1828. Its length was 363 miles. The drop from Lake Erie to the Hudson at Albany was 675½ feet, and the descent was accomplished by eighty-three lift locks. The immediate result of this waterway on commerce was to reduce the cost of freight from Buffalo to New York from $100 to $10 and later to $3 per ton. The report of the Engineer and Surveyor of the State of New York for 1905 gives brief sketches of the canals of this country, that are of much interest and great historic value. He schedules one hundred and forty canal projects in the United States, sixty-one of which have been abandoned. They were built to meet the

needs of a young country and its infant industries; the country has aged and the industries become giants too big for the cradles of their young lives. Canals that were built to accommodate large craft are used to-day as freely as were the little ones of the long ago. The canals that connect the Great Lakes have a commerce to-day that is a world wonder, and the country is awakening to the need of wide, deep, and safe waterways; not as rivals to railroads, but as helpers to meet the growing demand for means of transportation, and for cheaper transportation. Under the direction of the engineers, the little Erie Canal is being enlarged and rebuilt so that the limitation to the craft navigating it will not be two hundred tons per boat, but one thousand tons.

Then there is the call for coastal canals along the Atlantic seaboard; and for the Lakes to the Gulf Deep Waterway, of which the first link, the Chicago Sanitary and Ship Canal, was completed thirteen years ago. But the engineer as a canal builder reaches the zenith of his endeavor in the construction of the Panama Canal. Where the French engineer failed, the American engineer is triumphing over all obstacles, and another summer will see ships floating upon a new lake whose surface will be eighty-five feet above the level of the sea and under whose waters 164 square miles of jungle and tropic vegetation will lie submerged. This lake is reached by a marine stairway, each step of which has a rise of 28⅓ feet and a usable tread of 1000 feet, 110 feet wide. This lake is supplied by the waters of the rivers Chagres, Gatuncillo, the Rio Trinidad, and lesser streams. The dam behind which these waters are accumulated is an earth structure about 7000 feet in length. It is 300 feet thick at the water line, and its greatest thickness at the base is about 1800 feet. It rises to an elevation of 115 feet above sea level. The regulating works which control the outflow are located about midway of the length of the dam, and the flight of locks which I have spoken of as a marine stairway is located at the east end of the dam. These locks are twin structures. The usable length is 1000 feet, the inside width 110 feet, and the navigable depth over mitre sills 40 feet. The volume of concrete in these six locks is 2,085,000 cubic yards. When I visited this work in February, 1909—with the then President-elect, Mr. Taft—the

foundations for these locks were being tested. I was there in February of the present year, and in the interval between my visits 1,900,000 cubic yards of the total volume had been laid.

The lowest point in the divide through which the channel of the canal passes was originally 333 feet above mean sea level; the bottom of the canal, now nearly completed, will be forty feet above sea level; hence the cut in the lowest summit depression will be 293 feet, with a bottom width of 300 feet. The excavation from this cut is estimated as 93,882,000 cubic yards. The passage from Gatun Lake to the Pacific is through the Culebra Cut to the Pedro Miguel (twin) lock. The drop from this lock to the pool below is thirty feet, and the distance to the Miraflores locks is 1½ miles. There the drop of fifty feet to ocean level is accomplished by two locks (these locks are also in pairs). The building of the Pedro Miguel locks required 837,400 cubic yards, and the Miraflores locks 1,362,000 cubic yards of concrete. Simply to tabulate the volume of excavation and the cubiture of masonry, the depth and width of channels is a very tame and inadequate way of conveying an idea of the Panama Canal, which is a fitting theme for an epic in the poetry of great deeds. Its building is indeed one of those victories of peace more glorious than war, and the engineer has fought and won that battle for the Republic.

The little canals of the past were common carriers of no mean importance, for they helped to develop the country before railroads had entered in to possess the land, and the engineer built them.

But in the early days of the nineteenth century another sphere of usefulness demanded the skill, the courage, the genius, and the perseverance of the engineer. A new mechanical species appeared upon the earth which was destined to revolutionize transportation. The genus locomotive rolled over the world's horizon into the vision of mankind; a tiny thing at first, crude in its design and imperfect in its workmanship, but destined to increase and multiply and replenish the earth until its family in the United States numbered 58,947 in 1910; and as each decade passed, it grew in stature and in strength under the fostering care of the mechanical engineer. It is a far cry from Hedley's Puffing Billy of 1813 or Peter Cooper's Tom Thumb (1830) of 1½ horsepower to the Santa Fe Mallet freight locomotive,

which is 120 feet 7 inches long, weighs 308 tons without the tender, and has a drawbar pull of 111,000 pounds, but it tells the story of locomotive development almost at a glance. This is the work of the mechanical engineer, and the railroad engineer and the bridge engineer has had to provide the road-bed, tracks, and bridges upon which these iron monsters can travel with safety and speed. The response has always been equal to the demand. In 1833 the longest railroad in the world was from Charleston, S. C., to Hamburg, in that State, 135 miles. The latest statistics to which I have had access give the railroad mileage in the United States at the end of 1910 as 240,830.75 miles single main track, 21,658.74 miles of second track, 2206 miles of third track, 1488.78 miles of fourth track, and 85,581.93 miles of sidings and yard tracks, or a total of 351,766.59 miles. We were going some in those seventy-seven years. This was the condition of two years ago, but the statistics of two years back are stale and almost unprofitable in this prolific age of ours. Well, who has done all of this? Our friend, the engineer, with becoming modesty admits that he is the man.

In 1860 Arkansas had but 38 miles of railroad, California 23 miles; and in the areas now known as Colorado, Idaho, Kansas, Minnesota, Montana, Nebraska, Nevada, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, Wyoming, Arizona, and New Mexico there were no railroads, and in Texas there were but 307 miles of railroad. George H. Daniels, in his paper, "The Railroad's Part" (in "The Making of America"), says: "Forty years ago the Prime Minister of Japan, in answer to the question, 'How can we introduce civilization into the interior of Japan?' took a map and, drawing lines on either side of the range of mountains which extends for some distance through the centre of the Island Kingdom, said, 'Build railroads here and civilization will follow.'" Was it not true? Have we not seen that truth written many times across our continent? The occupation of the territory west of the Mississippi was a slow process. The city of St. Louis got its first railroad, the Missouri Pacific, in 1854. To-day it is one of the great railroad centres. The first notable movement of settlers to the west of the Mississippi was that of the Mormons in 1848, when persecution drove them from Illinois to a far country where they hoped to be let alone. The first transcontinental road

to be commenced was the Missouri Pacific, which was arrested in its progress by the "War between the States." The first sod for the Central Pacific was turned on the 23d of February, 1863. Work was commenced on the Union Pacific, November 12, 1865. Fourteen years, or till July, 1876, was the limit of time allowed by the charter for the completion of the enterprise, but the eastern and western sections met and the last spike was driven at the station of Promontory on the 10th of May, 1869 (see James Douglas's paper, "American Transcontinental Lines," in "The Making of America," vol. iv, page 275).

It was my good fortune to listen to an address given by General Granville Dodge at the annual meeting of the Western Society of Engineers, January 5, 1909. He was chief engineer of the Union Pacific during its construction period, and a part of his absorbingly interesting talk related to the building of that road. It was a story of intense interest, dealing with hardship, exposure to the dangers of Indian onslaught, unremitting labor under high pressure, and a memorable victory over all difficulties. Speaking of the backers of the road, he said: "They spent many millions for speed, and constructed a road two thousand miles long in three years. The line crossed the Rocky Mountains at an elevation of 8235 feet. From May, 1868, to May, 1869, we built 555 miles of main line and over 180 miles of side and temporary tracks." In 1870, so he told us, this veteran of the Civil War and time-tried engineer undertook the building of the Southern Pacific Railroad, which he completed in 1883. He said: "It is a singular fact that the same engineers and the same foremen who joined the tracks at Promontory Point in 1869 met on the plains of Sierra Blanco, Texas, in 1883 and joined the tracks which connected the second continental line across the country, but under entirely different circumstances. There were no bands, no crowds, no speeches, and no champagne."

The stories of the Northern Pacific, the Denver & Rio Grande, the Atchison, Topeka & Santa Fe, the Northwestern, the Rock Island, the C., B. & Q., and the Milwaukee & St. Paul, with all of their offshoots and feeders, if told without embellishment, would rival in interest the most fascinating romance. These railroads the engineer has built, and made the wildernesses habitations for man, and it is no mere figure of speech to say

that he has added to the Union all of the States west of the Mississippi, except Missouri, Arkansas, Iowa, Kansas, Minnesota, Texas, and California. He has done it.

Now we know about the 240,830 miles of main line that he has built, and we know that there were lots of bridges required for that length of line. Thomas Curtis Clark, in his paper on "Bridge Building" (see "The Making of America," vol. iv, page 395), tells us that "it has been estimated that there is one metallic bridge for every three miles of railway." Applying this rule to our single main track, we will have 80,276 metallic structures as the contribution of our bridge engineer to the building of our railroads. But he has not confined himself to railroads, and he has made wonderful strides in the development of his art since Howe was told that a train had passed safely over one of his bridges after the bottom chord had been burned nearly in two, and he explained it by saying "it was the principle that held it up." Wonderful structures span our rivers, our gorges, and carry traffic above our city streets. Captain Eads built the first steel arched bridge, and it stands to-day after a lapse of thirty-eight years, a thing of beauty and of strength, spanning the Mississippi and connecting St. Louis with its little sister city on the Illinois shore. To schedule the notable bridges of our own United States with the briefest description of each would expand this paper to most unreasonable length. Here in Philadelphia you have some beautiful examples of the bridge builder's ability to design and construct. In your neighbor city New York they boast proudly and justifiably of their first East River Bridge, built by Roebling, completed in 1883, with its span of 1595½ feet (still the largest suspension span in the world), which is crossed by more people than any other bridge in the country; their Williamsburg Bridge and their Blackwell's Island Bridge. We have notable structures widely scattered throughout our land, mostly metallic; but two masonry structures deserve special mention. The four-track arched bridge of the Pennsylvania Railroad crossing the Susquehanna River at Rockville, Pa., is a monumental structure, consisting of forty-eight segmental arches of seventy feet span, is one of these; and Flagler's Florida East Coast Railroad through the sea is another. It is a matter of pride with us that our engineer builds bridges so well and so economically that he is a successful com-

petitor with Old World fellow-craftsmen for structures on the Dark Continent and on the islands of the sea.

He builds dams, too, the highest, the strongest, and the most useful dams in the world. He builds them to conserve flood waters that would otherwise rush onward to the sea and mingle their wasted sweetness with the brine. These dams create great reservoirs, the outflow from which is used to irrigate lands, parched with immemorial thirst, and cause the grateful soil to "bring forth seed for the sower and bread for the eater." What he has done since the reclamation act of 1902 gave him his commission is concisely told in a statement sent me by Mr. Blanchard, statistician of the Department of the Interior:

"In the ten years of its work the service has built 7300 miles of canal. Placed end to end these canals would reach from New York to San Francisco and back. Several of these canals carry whole rivers.

"It has excavated 21 miles of tunnels.

"Its excavations of rock and earth amount to the enormous total of 93,000,000 cubic yards.

"Its roads have a total length of 626 miles; telephones, 2094 miles; levees, 70 miles.

"It has purchased 1,051,000 barrels of cement, and has manufactured in its own mill 340,000 barrels. As a result of its work, water is available for 1,159,234 acres on 13,000 farms.

"The gross value of crops produced on the lands irrigated by the Government projects in 1912 was estimated at $20,000,000. As a result of the work of the Government it is estimated that land values have increased more than $105,800,000."

Of the many notable structures erected in the prosecution of this work, I will only mention two. The Roosevelt Dam in Arizona is a rubble masonry, gravity structure, with horizontal arch. Its extreme height is 280 feet and its crest is 1170 feet. The volume of masonry is 338,452 cubic yards. In building this dam and the works auxiliary to it 401,175 barrels of Portland cement were used, and of that quantity 338,452 barrels were manufactured by the Government near the site of the work.

The Arrow Rock Dam in Idaho is the highest dam in the

world. It reaches a maximum height of 351 feet, and rises 260 feet above the bed of the stream; its crest is 1025 feet long, and its construction required 520,000 cubic yards of concrete masonry. In Washington, recently, I was privileged to listen to a lecture upon the reclamation projects of the Government, the interest of which was enhanced by a most beautiful series of stereopticon pictures.

We easily pass from dams built for irrigation and power to dams built for power purposes only, and to hydro-electric power developments at natural falls. In these developments the hydraulic engineer, the civil engineer, the mechanical engineer, and the electrical engineer make common cause, and all may be embodied in one man; but that would make him almost a phenomenal man. Whether it be team work or single harness, the results are wonderful and useful beyond measure. When hydro-electric developments come up for discussion, it would be strange if our thoughts did not turn to Niagara Falls, where, on the American side, two plants using 15,100 cubic feet of water per second are turning out 230,381 electrical horsepower, presuming that they are developing an efficiency of 80 per cent. There is a project, the plans for which have been submitted to me for advice, to take 6000 cubic feet per second from Lake Erie through a tunnel via Lockport and discharge it into Eighteen Mile Creek. This project proposes to utilize 312 feet of the entire fall from Lake Erie to Lake Ontario. If the 15,100 cubic feet per second used by the two existing powers were available for this latter project, that volume of water would yield 428,236 net electrical horsepower, or nearly twice the power now derived from it. There are many scores of water powers on our land which are interesting and more or less worthy of mention, but none possessing greater interest for the incarnate engineer than that now being constructed at Keokuk, Iowa, where the Mississippi is being held up and hereafter must pay toll in service before it can pass on its immemorial way in that channel which it has excavated for itself. This construction consists of a lock on the Iowa side built for the Government in return for the franchise under which the plant is being built. This lock is 110 feet wide, 400 feet of usable length, with forty feet of lift. Next comes the power-house, 123 feet wide, 1400 feet long, built to accommodate thirty turbo-

generators. Some idea of the immense size of these turbines may be conveyed by the fact that the diameter of the draft tubes is eighteen feet. The weight of each apparatus is five hundred tons. The dam extending across from the power plant to the Illinois shore consists of a series of arched spans, 119 in number, thirty-six feet centre to centre of piers, and clear opening of thirty feet. These piers are six feet thick and forty-two feet wide; each opening is closed by a dam rising thirty-two feet above the bed of the stream, vertical on its up-stream side and ogee on its down-stream side. There are steel gates moved vertically with power mechanism on the bridge overhead by which the outflow over the dams is regulated. These gates are eleven feet high and long enough to close the thirty feet of opening between the piers. This plan will develop 200,000 electrical horsepower. This power will be transmitted 150 or more miles from the power site. A large block of it has been sold in St. Louis, distant nearly 150 miles. The dam creates deep slack-water navigation for sixty miles up stream. The progress of this work is among the marvels of celerity in modern construction, and our engineer is doing it.

To-day our cities must fetch their water from afar, unless —like my home city, Chicago—they have built beside great natural reservoirs. The city dwellers go no more with pitchers to the town pump, for our engineer has brought them water from remote fountains. He has led it through sheltered ways, along mountain sides, across valleys, and beneath rivers, and the life-sustaining fluid flows responsive to the turning of a faucet within the homes of the city dwellers. Two of the most memorable examples of water supply brought from long distances are found in our own land. New York has had to go farther and farther afield for her water supply as years brought her added thousands of thirsty people. The last watershed which she has made her own, within which the Ashokan dam is to bar the outflow of water, save as man liberates it, must furnish its supply through ninety-three miles of aqueduct; fifty-six miles of this distance is in "cut and cover," fourteen miles in grade tunnels, six miles through steel pipe siphons, and seventeen miles through pressure tunnels. One of these pressure tunnels passes under the Hudson River, dropping down 1150 feet below the surface to find suitable material through which to bore it.

This is what our engineer is doing for the greatest city of our country on the Atlantic coast. He is doing even more things for a little city on the Pacific coast. He is building an aqueduct to carry water to Los Angeles from Owens Valley, into which Mount Whitney looks from its cap of everlasting snow, 14,502 feet above sea level, and around which twenty-three other peaks of lofty eminence are gathered; and all of these give of their melting snow to make Owens River, which drains 2800 square miles of area. This aqueduct traverses 230 miles of country that challenges the courage, the endurance, the skill and fidelity of the engineer, but he is meeting every demand of the mountains and the deserts, and as a result 260,000,000 gallons of pure water daily will flow through the channels he has created.

This work is unique, for it is absolutely municipal. The city of Los Angeles has reposed its faith in the chief engineer and the loyal men he has grouped around him. They have planned the work, organized the working force, about 5000 men, which they house and care for and direct. They manufacture the cement which is used in the work, and their progress has been record breaking, besides showing an economy which, compared with bids at first received, indicates that the cost will be about half of what it would have been had the work been let to contractors.

In our cities the engineer has been busy striving to provide adequate facilities to keep pace with the urban needs, for transportation, for sanitation, for light, for heat; to build harbors for our marine commerce, and to make convenient and economical provision for interchange between land- and water-borne commodities.

In the matter of sanitation, he builds sewers to carry off the noxious spewings of the city; he builds canals to carry away the effluents of the sewers; he builds filtration plants to remove impurities from potable water, and he builds other filtration plants to render sewage innocuous before it passes into natural streams.

The mining engineer has gone into the fastness of the mountains and into the deep places of the earth and brought out coal and gold and silver and all manner of precious things, adding to man's comfort and his usefulness, and his happiness as well.

The electrical engineer has carried us into new realms of light before which all previous illuminants pale their "ineffectual fires." He can tell you that electricity *is,* but he cannot tell you *what* it *is.* I was told some years ago at Niagara that when Lord Kelvin was there a short time previously he visited one of the power plants then in the process of construction. A young engineer—ignorant of the great personality he then encountered—was very kind in showing him over the work and telling him all that he knew about it. When they were about to part, Lord Kelvin said: "My young friend, you have been very kind and have told me some very instructive things. Let me ask you, 'What is electricity?'" The young man answered, "I do not know, sir." The great man said: "Then at last we stand upon the same plane." Not only can the electrical engineer tell you that electricity *is,* but he can demonstrate to you its wonderful usefulness in the fields of industry and art.

The engineer has borne his part in the building of the Republic, and may we not paraphrase Tennyson and say *what he has done,* but the earnest of the things that he shall do.

Interference Points with a System of Right-angled Prisms. H. SCHULZ. (*Phys. Zeitschr.,* xii, 1211.)—When a pair of right-angled prisms are placed with their hypothenuse surfaces nearly in contact, leaving only a thin film of air between, a peculiar system of colored points is seen on looking in a direction normal to the film, near the extremities of the hypothenuse. The phenomenon is explained by the crossing of two sets of interference bands. Both sets of bands are due to the splitting-up of rays by the thin film of air, but in one case the rays undergo reflection at the three interior faces of the upper prism before entering the film of air to form the bands; in the other case the rays undergo reflection at the three faces of the lower prism after the bands are formed by the film. In the first case the interference bands are seen direct, in the second they are seen reversed, and the two sets of bands appear crossed. The phenomenon may be rendered more conspicuous and extended over a wider region by silvering one side face of each prism. The higher the reflection coefficient of the hypothenuse, the more favorable the distribution of intensity for observation of the phenomenon. Under certain conditions, by suitably silvering the hypothenuse surface, both sets of bands may be seen double, resembling the appearance with polarized light. A later paper will deal with the resolving power of this prism-system, and the possibility of utilizing it to distinguish very small differences of wave-length.

RECENT DEVELOPMENTS IN STEAM TURBINES.*

BY

H. T. HERR,

Vice-President and General Manager, The Westinghouse Machine Company.

WESTINGHOUSE TURBINES.

In the early experiments made at The Westinghouse Machine Company, under the direction of Mr. George Westinghouse, a system of turbine elements was developed by Mr. Westinghouse consisting of a combination impulse turbine for the high-pressure stages, and reaction or Parsons elements for the low-pressure portions of the turbine, the object of the combination being to secure, without sacrifice in economy, a more stable mechanical construction by shortening the machine and dispensing with the necessity for three balancing pistons, as obtained in the Parsons design originally exploited.

This combination was particularly desirable at the time of its introduction by Mr. Westinghouse on account of the relatively low powers then required in turbo-generator work, although very successful machines have been in operation here and abroad of the straight Parsons design, which lends itself admirably to certain operating conditions.

The ability of the Curtis element to extract at a given blade speed considerable energy in the high-pressure stage of the turbine with good efficiency resulted in its adoption by Mr. Westinghouse for the high-pressure portion of his machine, by which 20 per cent. to 50 per cent. of the energy of the total expansion is extracted, leaving to the Parsons blading in the low-pressure portions of the turbine the balance of the work to be done with the most efficient turbine elements.

The impulse wheel in this construction replaced a large number of rows of Parsons blading with equivalent economy, because in the smaller powers it was necessary in the straight Parsons machine, on account of total peripheral admission, to make the blade speeds relatively low in order that their height

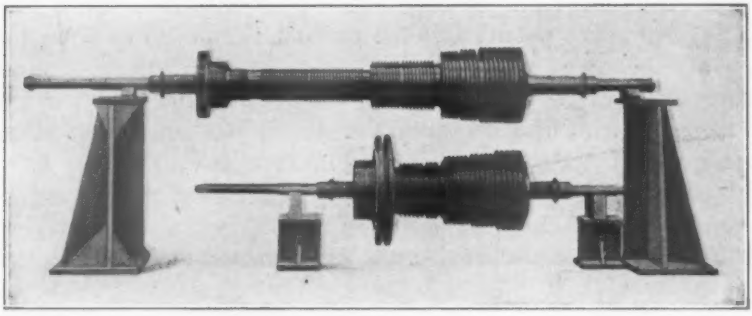
* Continued from page 128.

might be as large as practicable, to reduce the proportion of leakage by the end of the blades due to the necessary blade clearances. Such a construction of spindles is shown in Fig. 31, where the comparison is obvious.

As this development proceeded, the demand for higher capacity generators increased, and to meet this demand it was necessary to materially enlarge the low-pressure portions of the turbine, which, in some instances, required a dividing of the Parsons blading into two sections, commonly known as the double-flow low-pressure expansion.

In 1903 Mr. Westinghouse filed his application for patent on the combination impulse reaction double-flow turbine illus-

FIG. 31.



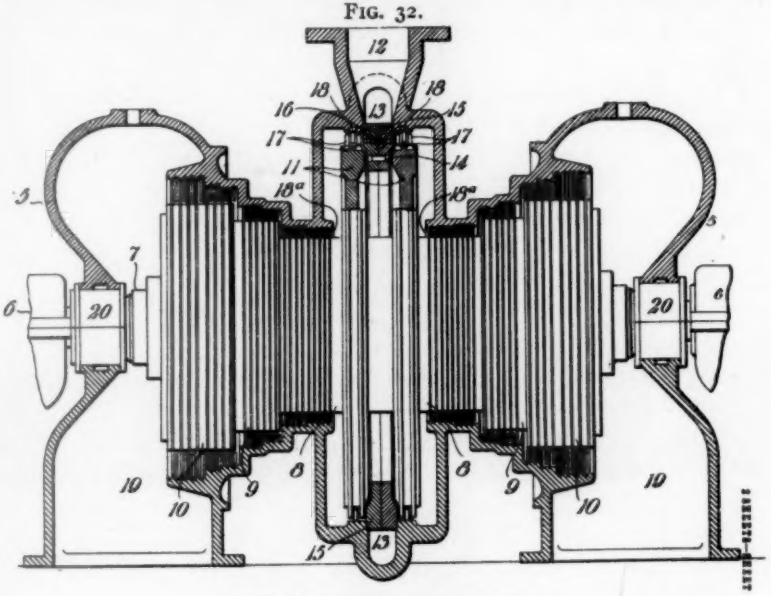
Rotors of two 500-horsepower steam turbines; upper spindle with complete reaction blading, lower spindle with impulse and reaction blading.

trated in Fig. 32. With this construction the balancing pistons required by the straight Parsons machine were entirely dispensed with, and while for double-flow construction twice the number of blades were required as for similar conditions with single-flow, yet the application of the impulse wheel to the high-pressure stages made possible, in a great many instances, the proper mechanical design, on account of the considerable shortening of the turbine due to the introduction of the impulse wheel, thus allowing a length of spindle and cylinder of proper mechanical stability.

As this development progressed it was found advisable, on the score of efficiency, to resort to the Westinghouse single double-flow construction. This differs from the straight double-

flow principle in utilizing a single Curtis impulse wheel with two rows of revolving blades, followed by a single barrel of

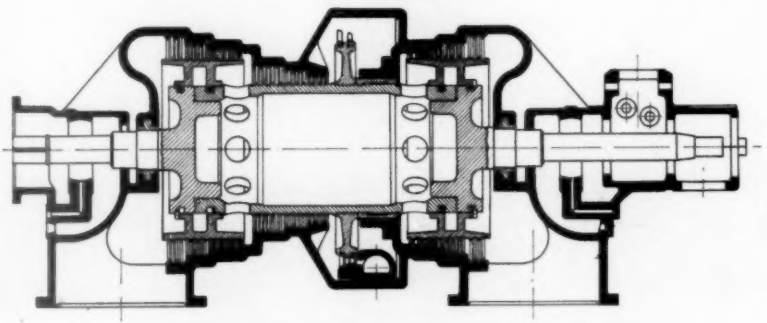
FIG. 32.



G. Westinghouse fluid pressure turbine.

reaction blades, after which half of the steam is allowed to pass through the drum around a balancing piston (for the single

FIG. 33.



Turbine assembly, longitudinal section. Semi-double-flow turbine.

barrel of Parsons blades) to half of a double-flow expansion of reaction blading, and thence into a double exhaust opening at

either end of the turbine, as illustrated in Fig. 33. The intermediate reaction blading was thus allowed to be proportioned with blades of twice the height and half the number as would have obtained had the entire reaction blading been made double-flow.

Since the efficiency of reaction blading is a function of its length, assuming the blade clearances the same, it is apparent that this single double-flow construction is adaptable to turbine units of moderately high capacity, depending on the rotative speed. This construction is now used in turbo-generator units for alternating current from 3000 to 10,000 kilowatts at speeds of 1500 to 1800 revolutions per minute.

In the development of the higher-powered turbo-generator units (above, say, 10,000 kilowatts at 1500 or 1800 revolutions), owing to the large volume of steam handled, the best proportioning results by making the reaction blading double-flow with a Curtis impulse wheel carrying two rows of blades and utilized in the high-pressure portion of the turbine. Here the reaction blading may be operated at sufficiently high blade speeds to materially reduce the number of rows and make a comparatively short machine, notwithstanding the fact that twice the number of rows of blades are required on account of the double-flow principle than would be necessary if single-flow elements were resorted to. Fig. 34 shows such a construction for a machine of 15,000 kilowatts, maximum rating at 1800 revolutions per minute.

These various constructions have, as will be seen, their particular field of usefulness, depending on the operating conditions and the speeds for which the turbines are designed.

The great importance in the turbine art of this combination turbine has been realized principally in the past five years in the field of electric-power generation, because it gives great flexibility and permits the use of high pressures and high superheats without the deleterious effect these operating conditions might impose with the more difficult mechanical construction of long cylinders and spindles subjected to wide ranges of pressure and temperature. The effect of the combination machine may perhaps better be understood by taking the following practical example, which assumes operating conditions now common in Europe and being introduced in this country:

FIG. 34.

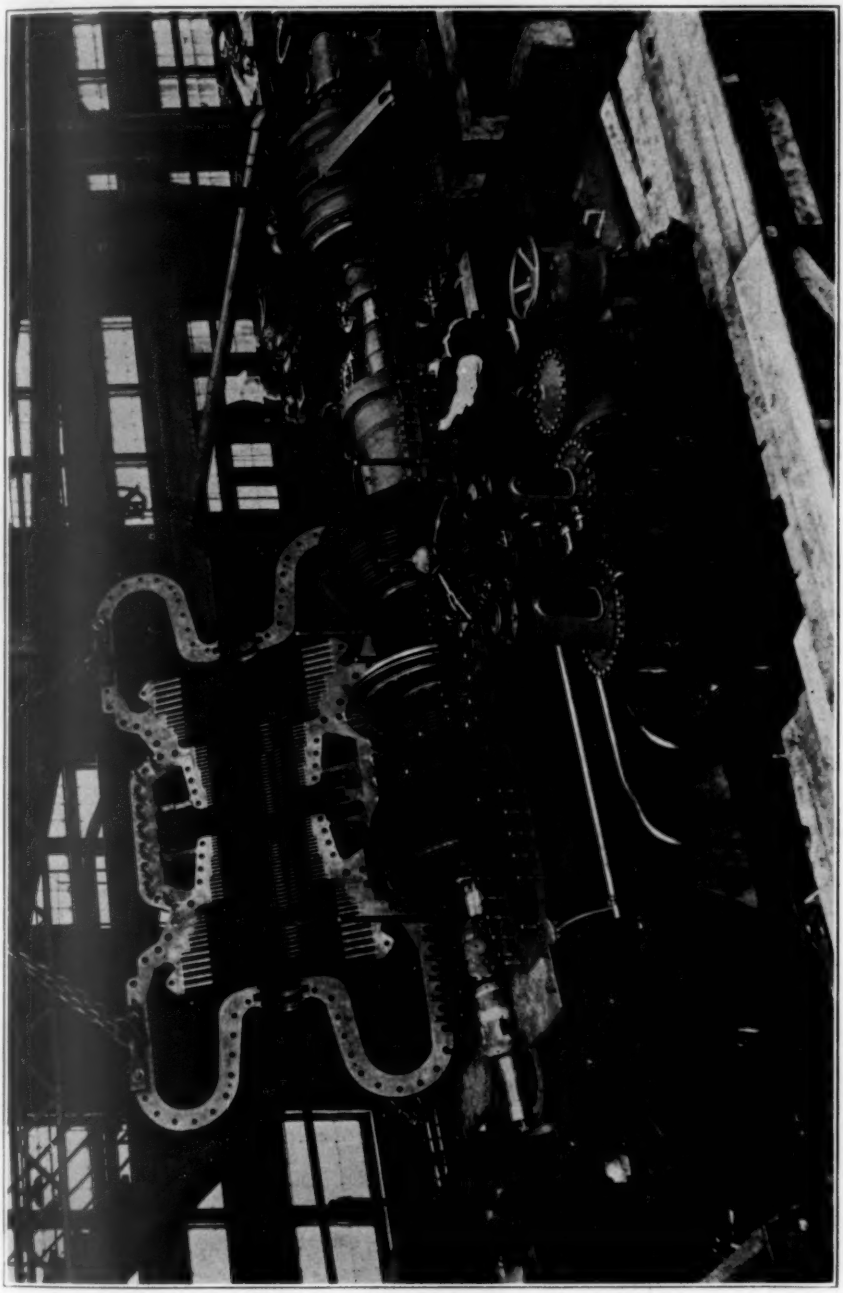
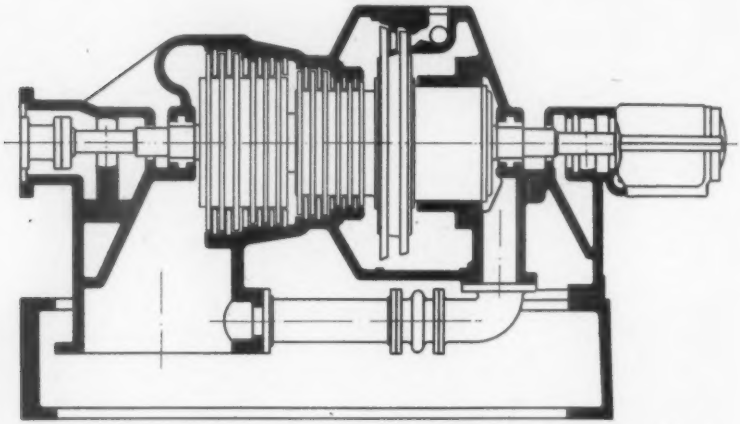


FIG. 34.

10,000-kilowatt turbine. Built for the City Electric Company, San Francisco.

Steam is to be delivered to the turbine at 200 pounds pressure gauge and 150 degrees superheat, and is to be expanded to 28½ inches vacuum. Its temperature, therefore, entering

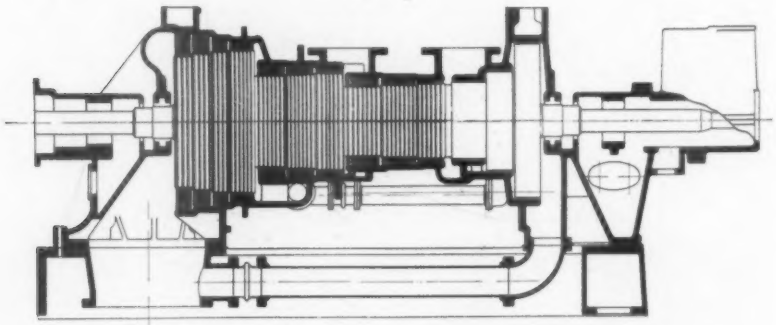
FIG. 35.



Turbine assembly, longitudinal section. Single-flow turbine with impulse element.

the turbine would be 538° F. With the Westinghouse turbine the steam would enter the nozzle chamber and be expanded through the nozzles to 78.8 pounds absolute with the impulse

FIG. 36.



Turbine assembly, longitudinal section. Single Parsons type turbine.

wheel operating at a blade speed of 500 feet per second. Its temperature and pressure would therefore be in the impulse chamber 328° F. and 78.8 pounds absolute respectively, which

are sufficiently low to give an entirely satisfactory mechanical construction of the low-pressure end. The construction of such a turbine is shown in Fig. 35. If the steam expansion were to take place in the equivalent Parsons turbine, the construction would be as illustrated in Fig. 36. By comparing the two it will be seen that a very material shortening of the spindle is secured by the replacement in the Parsons turbine of the high-pressure portions, corresponding to the equivalent expansion as would take place in the nozzles of the impulse wheel, and with the same efficiency, because the impulse wheel replaces the most inefficient portion of the Parsons turbine.

In the matter of economies at fractional loads the substitution of the impulse element for its equivalent Parsons blading in the high-pressure portion of the turbine allows greater efficiency, because, with the impulse construction, nozzle control can be resorted to, thus converting into useful work a portion of the energy of the steam which would be lost in a straight Parsons turbine due to throttling. In other words, with the nozzle control construction the impulse wheel becomes an efficient reducing valve when the turbine is operated at fractional loads.

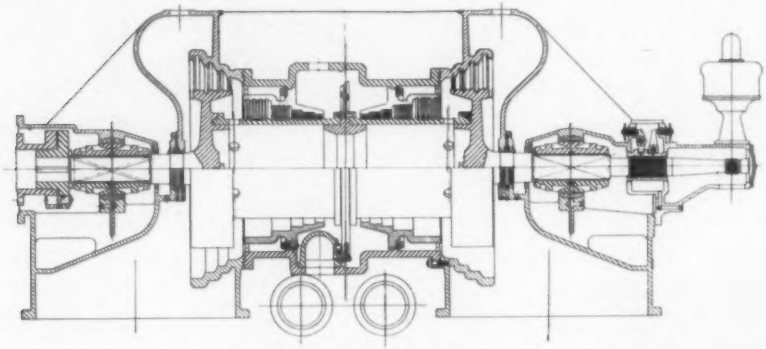
While this advantage may not in a good many instances be very material, and may not warrant the ordinary complications incident to nozzle control, yet in principle it is proper to utilize it for the same flexibility with greater efficiency, and it is only necessary to design a mechanical nozzle control apparatus whose complication is less than the advantages gained by the economies in its use in order to make this arrangement a most satisfactory and desirable one.

The great flexibility of reaction blading over wide variations of pressure distribution, and its adaptability especially to handling large volumes of steam efficiently, make its application particularly desirable in the low-pressure portions of turbines. There are, however, operating conditions now arising in power-plant development which make more suitable the adoption of reaction blading for the high-pressure portion of turbines than has heretofore obtained. This condition has been particularly brought about by the development of the alternating-current generator to operate at high speeds, generating large power. This can probably best be illustrated by some recent

designs prepared by The Westinghouse Machine Company for generator units of 15,000, 20,000, 25,000, and 30,000 kilowatts capacity.

In such units it is of the utmost importance to secure the

FIG. 37.

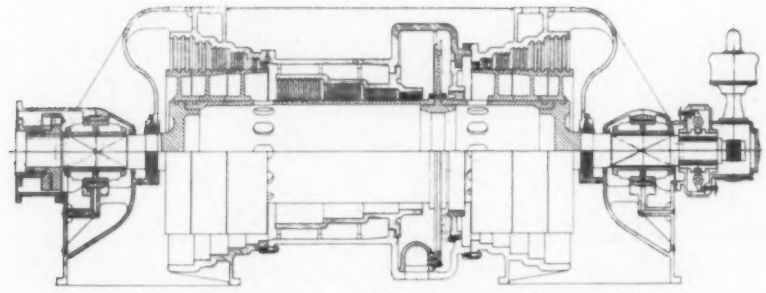


25,000-kilowatt steam turbine, condensing, 1500 revolutions per minute

very maximum of economy in steam consumption, because the output of the units is so enormous that a small loss in efficiency means a very large increase in the cost of operation.

With the development of the electrical art, alternating-current generators of 5000 kilowatts can be built at 3600 revo-

FIG. 38.



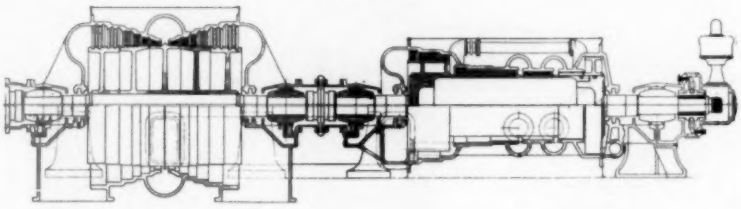
25,000-kilowatt steam turbine, condensing, 750 revolutions per minute.

lutions per minute, from 5000 to 25,000 kilowatts at 1800 revolutions per minute, and from 5000 to 30,000 kilowatts at 1500 revolutions per minute, the different speeds corresponding to 60 and 25 cycles, as used in this country. Likewise, the tur-

bine is susceptible of generating in one unit the necessary power to drive the above generators at these particular speeds.

Some two years ago designs were proposed by The Westinghouse Machine Company for a 25,000-kilowatt unit to operate

FIG. 39.

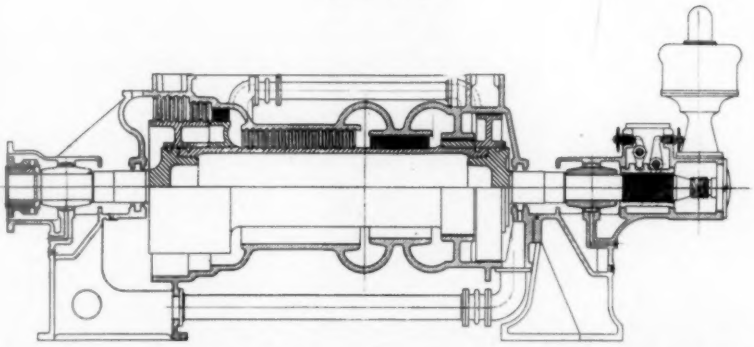


20,000-kilowatt steam turbine, 200 pounds boiler pressure, 750 revolutions per minute, condensing.

a 25-cycle generator with operating conditions of 200 pounds steam pressure, 200 degrees superheat, and 29.2 inches vacuum.

Four solutions of this condition were worked out, as follows: (1) A Westinghouse double-flow turbine at 1500 revolutions per minute, direct connected to a 25-cycle generator of 25,000 kilowatts maximum capacity, as illustrated in Fig. 37.

FIG. 40.

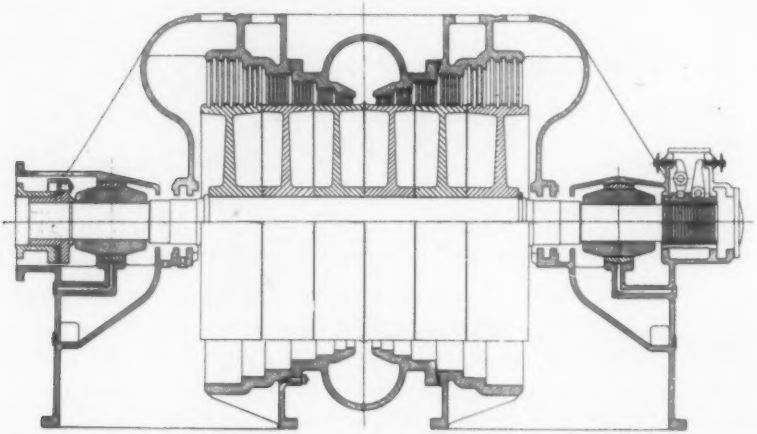


20,000-kilowatt steam turbine, high-pressure element, 200 pounds boiler pressure, 1500 revolutions per minute.

(2) A single double-flow Westinghouse turbine running at 750 revolutions, direct connected to a 25,000-kilowatt generator, as illustrated in Fig. 38. (3) A tandem compound Westinghouse-Parsons turbine at 750 revolutions per minute, the high-pressure portion being single-flow and the low-pressure portion being double-flow, direct connected to a 25,000-kilowatt

generator, as illustrated in Fig. 39. It is evident that this machine could be arranged cross-compound with two generators of 12,500 kilowatts each. (4) A cross-compound Westinghouse-

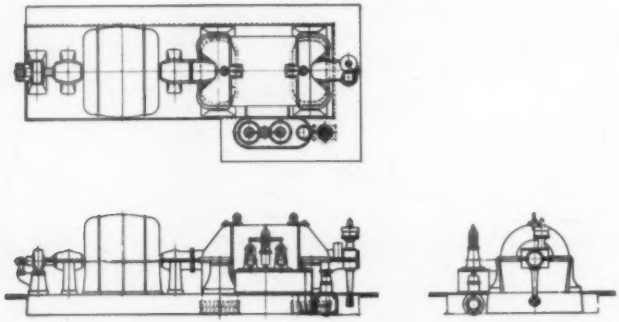
FIG. 41.



25,000-kilowatt steam turbine, cross-compound condensing, high pressure 1500 revolutions per minute, 750 low pressure revolutions per minute. Section through low-pressure cylinder.

Parsons turbine with the high-pressure portion running at 1500 revolutions (Fig. 40), direct connected to a 12,500-kilowatt generator, and a double-flow, low-pressure, Westinghouse-Par-

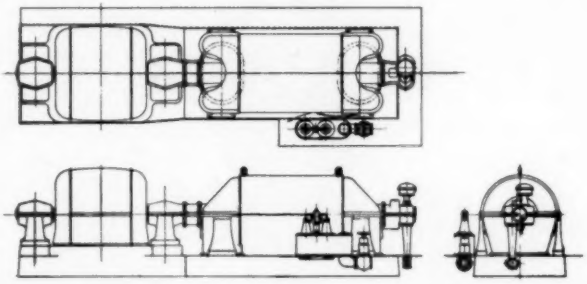
FIG. 41A.



sons turbine running at 750 revolutions, direct connected to a 12,500-kilowatt generator, illustrated in Fig. 41. Fig. 41A shows the comparison to scale of the machines in 1, 2, 3, and 4 respectively.

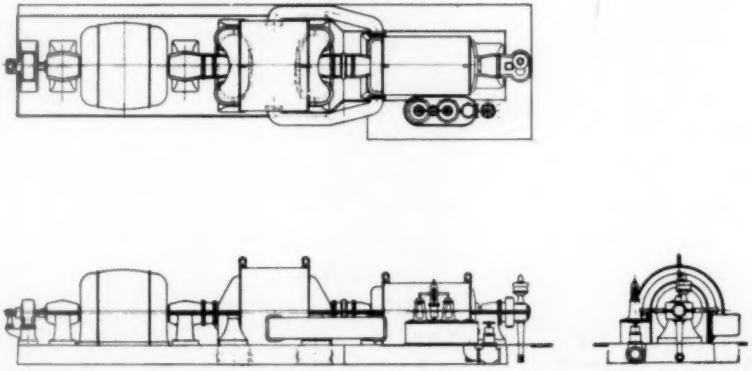
All of these arrangements would give very excellent economy, and the choice of the unit would depend primarily on the two factors of first cost and economy, assuming that in each case the reliability for continuous operation is the same.

FIG. 41B.



A close study of the four arrangements indicates that the Westinghouse double-flow turbine at 1500 revolutions per minute, direct connected to a single generator (Fig. 37), is the cheapest construction. The large areas required in the low-pressure stages of this turbine make high velocity and long

FIG. 41C.

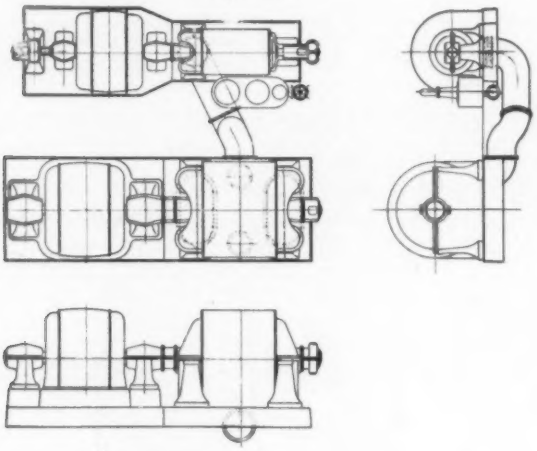


length of blade essential, with the necessity of careful designing to properly take care of the stresses due to centrifugal force in the low-pressure end.

The most economical combination of the four is the cross-compound Westinghouse reaction turbine with the high-pressure portion running at 1500 revolutions and the low-pressure por-

tion at 750 revolutions. With this arrangement the highest efficiency is obtained, because with the large volumes of steam required to develop the high power and the ability to combine the unit into high- and low-pressure cylinders, running at 1500 and 750 revolutions per minute, gives the condition for best blading proportions throughout the turbine without departing from standards of practice already established. This machine would be very remarkable for its high efficiency, which it is believed could not be reproduced with any other known form of turbine. The construction, however, is considerably heavier

FIG. 41D.



than the single unit commented upon above, and would be more costly to construct and install.

In such a case as the one cited there is little doubt that the cross-compound Parsons machine will give the maximum efficiency. At powers and speeds attainable with single alternating-current units of, say, below 15,000 kilowatts capacity the Westinghouse double-flow turbine between 10,000 and 15,000 kilowatts will be nearly, if not equal, to the cross-compound straight reaction turbine under like operating conditions, and any difference in efficiency would probably be offset by the difference in first cost in favor of the Westinghouse double-flow machine. Between 10,000 and 4000 kilowatts capacity the Westinghouse single double-flow machine would undoubtedly be

the proper construction, taking into consideration the first cost and efficiency.

The demand for turbo-generator machines is greatest in kilowatt output between the sizes of from 4000 to 15,000 kilowatts maximum rated capacity, within which range the Westinghouse single double-flow and Westinghouse double-flow machines most admirably meet the commercial conditions both with respect to cost and efficiency.

Below 4000 kilowatts capacity the Westinghouse turbine consisting of (1) an impulse wheel followed by single-flow reaction blading, illustrated in Fig. 35; (2) an impulse wheel followed by single double-flow reaction blading (Fig. 33); (3) an impulse wheel followed by double-flow reaction blading (Fig. 37), and (4) a single-flow Westinghouse reaction turbine (Fig. 36), represent the various choice of machines best suited for operating conditions (*a*) dependent on the initial pressure and superheat, (*b*) on the number of revolutions at which the generator or other driven machine rotates, and (*c*) on the capacity.

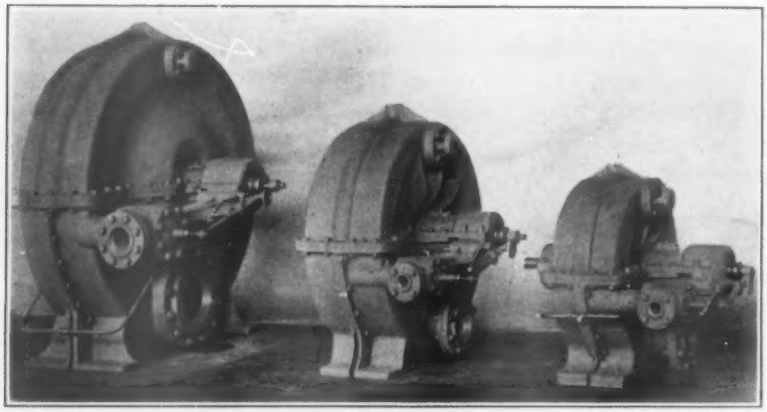
Thus with a speed of 3600 revolutions per minute, driving a 60-cycle generator at, say, 3000 kilowatts, the turbine design would follow the combination impulse double-flow reaction machine for best efficiency and lowest cost (Fig. 37). If, however, the generator to be driven was 25-cycle, with an allowable maximum speed of 1500 revolutions per minute and a capacity of 3000 kilowatts, the choice would lie between a design of a straight single-flow reaction turbine and a combination impulse single-flow reaction turbine, the former being used for moderate degrees of superheat and initial pressure, and the latter for high superheat and high pressure.

In general, however, the application of the Westinghouse turbine, consisting of an impulse element for the high-pressure portion and reaction blading for the low-pressure portion, is admirably adapted for complete expansion turbines over wide ranges of power and speed, and since the introduction of this type in 1903, following the initial designs by Mr. Westinghouse, a large proportion of the firms building steam turbines have utilized this construction, either with Parsons or Rateau blading, following the Curtis impulse element or elements in the high-pressure end.

The advantages of the Westinghouse type are: (1) the

ability to shorten the machine by the introduction, in the high-pressure stages, of an impulse wheel of the Curtis type without material loss in efficiency where the powers and speeds are relatively low; (2) the reduction of pressure and temperature within the turbine cylinder by expanding the steam initially in fixed nozzles; (3) the elimination of two or more balancing pistons as obtain in the straight Parsons machine, consequently reducing the small, balancing piston clearance, and leakage of steam incidental to their introduction; (4) the retention of the most efficient turbine elements in that portion of the machine

FIG. 42.



Group of S. N. C turbines.

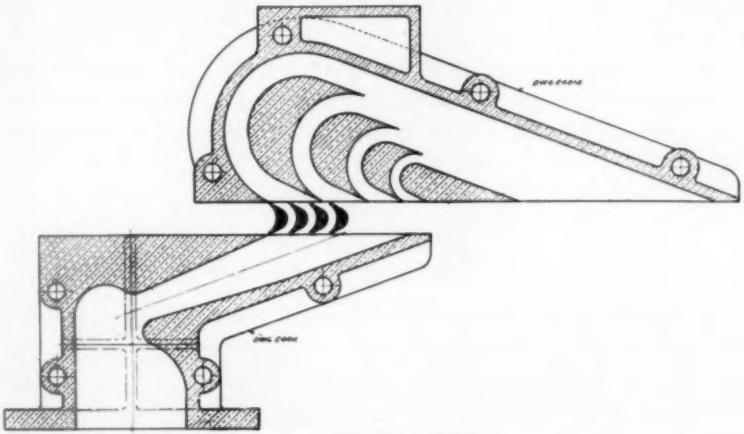
where they can be most effectively employed for efficiency; (5) the ability to secure higher economies at fractional loads by the introduction of nozzle control on the initial impulse element; and (6) the retention of the drum construction for rigidity of spindle and low cost of manufacture, referring particularly to the reaction blading.

The disadvantages of the Westinghouse construction are: (1) for extremely high powers, say, above 15,000 kilowatts capacity, the impulse wheel is less efficient than its equivalent Parsons blading, depending, however, on blading proportions; (2) for capacities of 300 kilowatts at 3600 revolutions per minute, and 750 kilowatts at 1500 revolutions per minute, the construction, while applicable at these powers and speeds, becomes

as expensive with the same efficiency as turbines of other designs.

For the smaller powers, therefore, The Westinghouse Com-

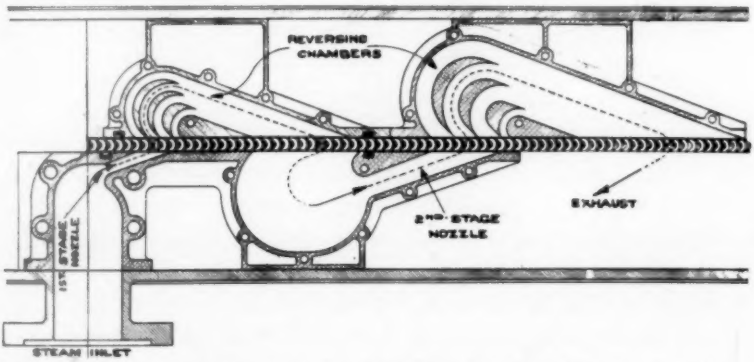
FIG. 42A.



S. N. C. turbine. 05 S. N. C. nozzle blocks and reversing chamber.

pany developed some three years ago impulse turbines of the re-entry type, illustrated in Fig. 42, which are adaptable down to units of 1 kilowatt capacity, having the advantage of one revolv-

FIG. 43.



S. N. C. turbine. Arrangement of nozzles and reversing chambers, showing action of steam. Two stages, with two velocity drops to each stage.

ing row of blades, with which it is possible to obtain (*a*) a subdivided impulse turbine with one reversal (Fig. 42A), equivalent to a Curtis turbine with two revolving rows of blades, used for

medium-pressure drops; (*b*) a subdivided impulse turbine with two reversals (Fig. 43), equivalent to two Curtis elements with four revolving rows of blades, and (*c*) subdivided impulse elements with one or two reversals followed by one or more Rateau stages, or a series of Rateau stages without Curtis elements.

This construction has the advantage of the simplicity of the De Laval turbine operating efficiently at such rotative speeds as are commercially required for the purposes of direct connection to generators, pumps, blowers, and other machines which require relatively good efficiency with relatively low speed of rotation.

COMPARISON OF STEAM TURBINES.

Comparison of the relative merits of the turbines previously described cannot be fairly made in any general terms, as certain combinations of turbine elements must be varied to suit the particular operating conditions which may be imposed. If, however, the discussion be limited to the most common type, namely, the complete expansion turbine and its operating requirements, subdivided with definite conditions imposed, the general condition influencing the selection of a good type may be stated.

The three principal items in considering the complete expansion turbine for commercial purposes are (1) reliability, (2) capacity, (3) economy.

RELIABILITY.

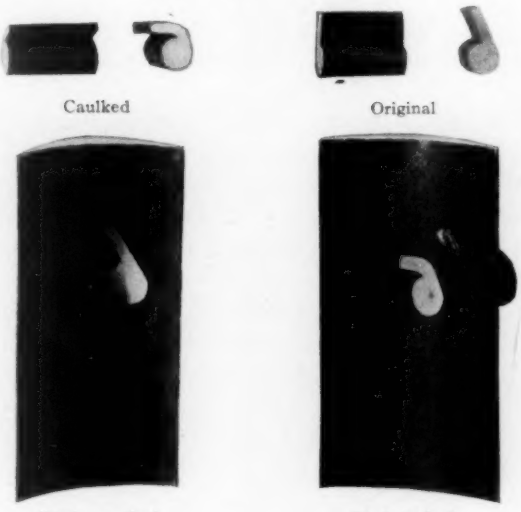
In general, it may be stated that the reliability of turbines of different types depends more on the design of the details than on the inherent merits of the turbine elements themselves.

One of the principal items in detail design to which all turbine builders pay particular attention is the method of fastening the blades to the disks or drums, as the case may be. For many years after the introduction of the Parsons turbine the blading was secured to the drums by the well-known method of inserting, alternately, in a slightly dovetailed groove, the blades and packing pieces, and after a row had been so inserted in its groove, the packing pieces were caulked between the blades, to secure them by friction, as well as by a small nick in the base

of the blade. As the development in turbine design progressed it was found necessary with longer blades to lash the ends in some manner. Some ten years ago this was accomplished by silver-soldering a strip into the blades to secure the desired rigidity, but principally to prevent their vibration, due to their rotative speed and the velocity of the steam passing through them.

This general method of blading was devised by Mr. Parsons in 1896, and has been followed for a number of years by builders

FIG. 44.



Samples of the Westinghouse blade lashing.

of that type of turbine. To those skilled in turbine blading work the caulking process is known to be an excellent blade fastening. The first change which was made in this country in the Parsons form of blading was in the adoption of a different method of shrouding the blades, which consisted of punching a hole, in the shape of a comma, near the end of the blade and inserting therein a wire, drawn to the comma section. After the blades have been inserted in the spindle and cylinder and the comma wire put in place, a tool is used to shear the tail end of the comma at each blade and bend it around, as illustrated in Fig. 44. When this operation is performed, it is evident that there exists between

the blades a tight strut which effectively diminishes the tendency to vibration, is easily applied, and makes a much better and safer construction than the old method of silver-soldering. This construction substantially amounts to shrouding the blades without, however, creating any blank space between the real tip of the blade and the cylinder or spindle.

This lashing or shrouding of the blades prevents their individual vibration, but does not prevent their vibrating as a group.

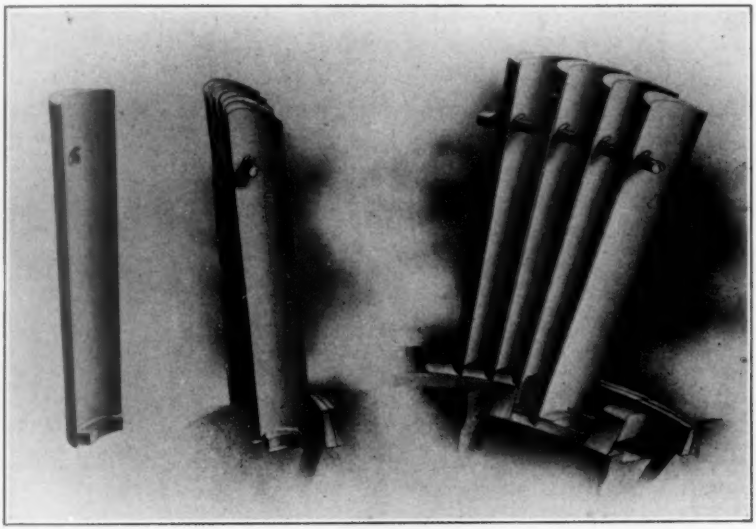
It is a fair statement to make that scarcely any turbine of anybody's make ever gave trouble due to the blades breaking or coming out because of centrifugal force. It is not centrifugal force that breaks the blades, but vibration of the blades themselves, and until lashing of the longer blades was resorted to, breaking was occasioned by the individual vibration. The lashing or shrouding of the blades therefore reduced very materially this difficulty. Twelve years ago The Westinghouse Machine Company experienced some unaccountable breaking of blades which were made of bronze. This was attributed to fatigue of the metal of the blade, or repeated heating and cooling, and led, as a cure to the difficulty, to the adoption of steel as blade material. Later experience and analysis of these troubles reversed the impression first obtained and led to the conclusion that the difficulty was really due to blade vibration.

In the last few years the capacities of turbines have increased so enormously, resulting in long blade lengths, that it became necessary to devise better means of insuring blade stability, and with this in view the Westinghouse Company has developed in the past two years the blade construction illustrated in Fig. 45. The lashing or shrouding must not be continuous, as provision for expansion and contraction must be made, since the coefficient of expansion of the spindle or cylinder, as the case may be, is not the same as that of the blades, the material being different. Therefore, all lashed or shrouded blades must be arranged in segments not exceeding, say, two feet in length for large diameters. There is no reason, however, why the segments of blading will not vibrate as a whole, just as the individual blades do when not properly lashed, except that on account of lashing or shrouding the frequency of vibration will be very much higher, and the amplitude consequently less. Lashing or shrouding, therefore, is a palliative against

vibration, and not a cure. It is the practice of the firm with which I am connected to lash all reaction blades above one inch in length, and very long blades may have as many as three or four rows of lashing wire.

The desirable thing, therefore, in turbine blading is to provide a blade which, since it is impossible to entirely eliminate vibration, will be of such form that the vibration, should it exist, will not concentrate the stresses at any one point. A turbine blade might be likened to a leaf spring secured at one end,

FIG. 45.



Turbine blading.

with the other end free to vibrate. If this leaf spring has a tapering section so that when loaded at its outer end the stresses throughout are uniform, it may be allowed to vibrate indefinitely without breaking. If the condition is reversed and the greatest section of the spring is at the outer edge, it will, on being deflected, have such deflection concentrated at the inner end close to the point of support. The concentration of these stresses at the supporting point would, in a short time, cause failure of the material and the breaking of the spring. If the spring were made of a uniform section throughout its length the

condition would, of course, be better than that as last stated, but it would be a question of sufficient time and sufficient amplitude of vibration for the fracture to take place at the point of support.

Some turbine builders diminish the section of the blade at the point of support; others maintain a straight section, while in the modern development of the Westinghouse construction (Fig. 45) the base of the blade where it is inserted in the spindle or cylinder is, in the process of manufacture, upset to a thicker section than at any other portion, such thickening extending beyond the point where the blade issues from the groove. It will also be noticed that there is provided an absolute interlocking system, the strength of the under-hanging foot of the blade being equal to that of the blade itself; also that this construction involves no caulking process which requires skill and is difficult to inspect. The foot at the ends of the blades is obtained by upsetting or forging, and the dies for carrying out this operation are so constructed that the blade material is increased at the root, tapering off to a standard blade section some distance above the surface of the blade-carrying member. This effectually eliminates concentration of stresses at the root of the blade and gives a construction approximating a beam of equal stress.

The advantages, therefore, of this new type of reaction blading may be summarized as follows:

(1) Absolute interlocking of the blades with the blade-carrying member, the strength of all fastening means being equal to the strength of the blades themselves.

(2) No caulking is employed. This permits ready inspection of the blades before insertion, and assurance that they are firmly secured when installed.

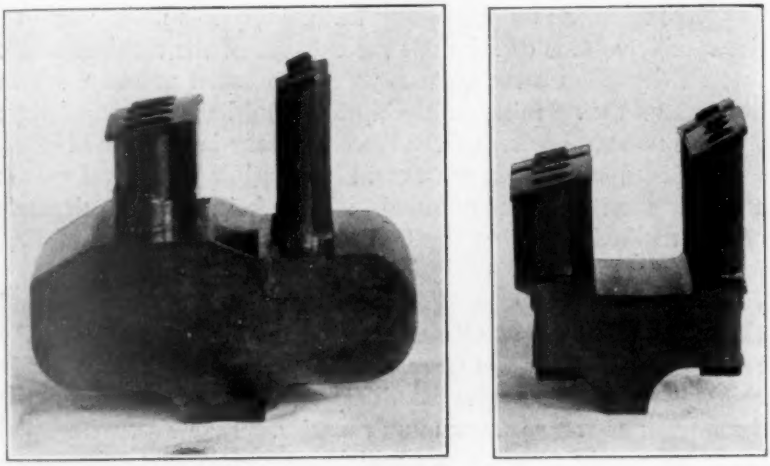
(3) The blades may be easily removed from their grooves and replaced an indefinite number of times without mutilation or injury to the grooves.

(4) The section of the blading is tapered, being heavier at the root, eliminating danger from vibration of the blades.

Development in blade-holding means for impulse turbines has been necessitated in the last two or three years, due to the increase in blade speeds. Prior to three years ago the blade speeds of the impulse wheel of the Westinghouse type did not exceed 400 feet per second. The blade fastening in the con-

struction used in these wheels is as shown in Fig. 46. The more recent developments, however, with the increase in impulse blade speeds, have resulted in the construction shown in Fig. 47, which materially reduces the weight of the impulse wheel at its head, and consequently the stresses in the disk, at the same time giving a blade fastening which is as strong as the blade itself. With this arrangement blade speeds of from 600 to 700 feet per second may be obtained without undue stresses in a through disk construction.

FIG. 46. FIG. 47.



Blade fastenings.

Many details of design have been refined as the development of the turbine has progressed, such as better proportioning of cylinders and spindles to withstand distortions due to differences in temperatures, the supporting of the cylinders on the bed-plates, details of nozzle construction, balancing pistons, etc. Space will not permit a minute description of these recent developments, but it may be stated in general that in the early Parsons construction in 1900 it was thought impracticable to build units of larger capacity than 400 or 500 kilowatts without subdividing the cylinder construction into high- and low-pressure portions. The turbine represented in Fig. 30, constructed in 1901, marks a distinct advancement in the art in this respect, and was at the time of its introduction severely criticised for its large capacity,

and predictions were made for its failure in service. This machine might be said to have been the forerunner of the enormous development in power capacities in turbine work, which to-day reach an output of from 20,000 to 30,000 kilowatts in a single cylinder.

MAXIMUM OUTPUT OF TURBINES.

It is evident that the De Laval turbine cannot be utilized for large capacity, and the comparison will therefore have to be made between the Westinghouse or Parsons turbine, the Rateau turbine, and the Curtis turbine.

The maximum output of any turbine depends mainly on (1) the specific volume of steam at the exhaust of the turbine, which in turn depends on the vacuum; (2) the outlet velocity, which depends on the permissible leaving loss, and hence the efficiency; (3) the mean diameter of the blading of the last row of blades, which depends upon the maximum permissible peripheral speed; and (4) the maximum permissible blade height, which depends on the method of fixing the blade and the construction of that part of the spindle holding the last row of blades.

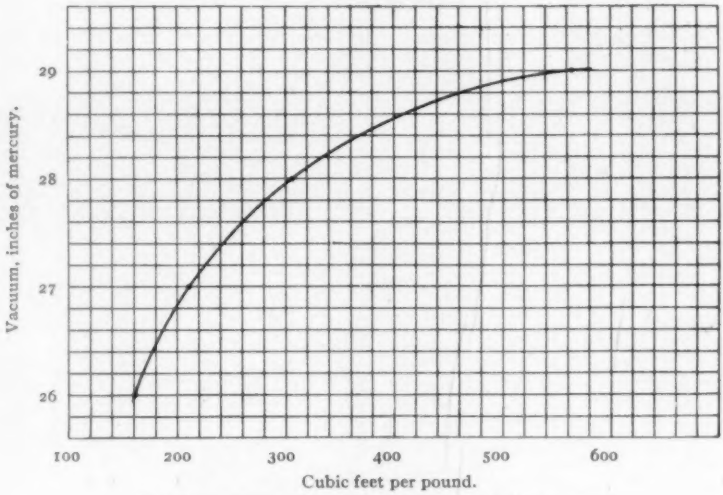
(1) Other things being equal in the Parsons, Rateau, and Curtis turbines, the specific volume of the steam passed by the last row of blades is the same, and with like blade speeds, blade heights, and blade angles no difference can exist between the three types as regards maximum capacity. Likewise, with equal blade speeds the leaving loss will be proportional to the outlet velocity. The maximum capacity of output, therefore, is dependent primarily on the length and mean speed of the last revolving row of blades and on the mean blade diameter, in any type of turbine. If a drum construction is used to carry the last row of blades, it can be shown that (other conditions remaining the same) a disk turbine can be built having twice the maximum output of a drum turbine. By those familiar with turbine construction, reaction blading is generally coupled with a drum construction. The recent designs of the Westinghouse high-power turbines, however, have the last rows of blading carried by a through disk and not by a drum, as may be seen by reference to Fig. 37.

The construction of the blade fastening in the Westinghouse turbine can be shown to be as strong as the blade itself; conse-

quently the limit of output, considering the last row of blades in this type of turbine, would be proportional to the permissible stresses in a through disk, which allows, therefore, the maximum capacity that any turbine is capable of, and particularly so as the construction of the Curtis and Rateau machines involves a disk with a hole in the centre, which, as shown in Appendix III, cannot be as strong and reliable as a disk without a hole in the centre.

The specific volume of one pound of steam expanding adia-

FIG. 48.



Specific volumes between 26 inches and 29 inches vacuum.

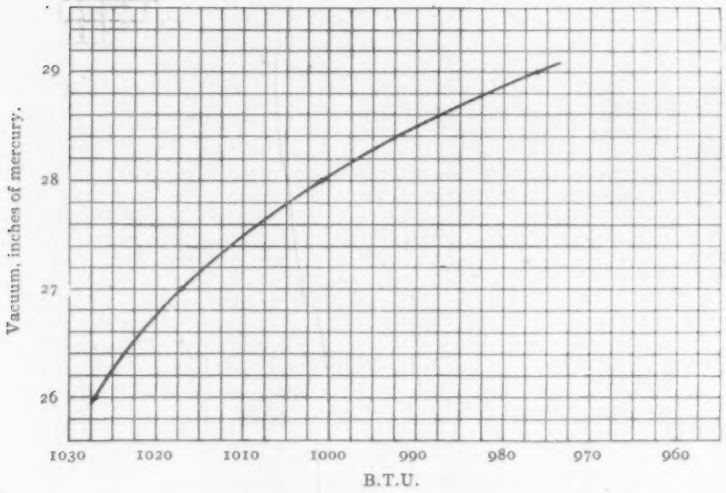
batically from 26 inches to 29 inches vacuum is plotted on the curve, Fig. 48. With a disk speed of 500 feet per second in the low-pressure end of the turbine there will be required, with reaction blading, two moving rows to complete the expansion from 26 inches to 29 inches vacuum. The height of the revolving blades to accommodate the increase in specific volume between 26 inches and 29 inches vacuum will be relatively as 1 to 3.4, depending somewhat on the capacity of the machine.

If the leaving losses in a Rateau or Curtis turbine are to be the same as in the reaction turbine, the last blades must be of equal length and equal speed for the same leaving loss and capacity, since the last moving row of the reaction turbine for

like efficiency may be made an impulse blade, which would result in a reduction of the blade height compared to what it would be if made for pure reaction.

The energy in the adiabatic expansion of one pound of steam from 26 inches vacuum to 29 inches vacuum is plotted in the curve in Fig. 49, from which it will be seen that between 28 inches and 29 inches vacuum the energy is practically the same as between 26 inches and 28 inches vacuum. With turbines of high capacity, therefore, it is essential to obtain very high vacuum in the exhaust on account of the enormous energy contained in

FIG. 49.



Energy in B.T.U. between 26 inches and 29 inches vacuum.

the expansion at low pressures. If we assume, therefore, that turbines of high capacity are built for operating conditions with high vacuum, say 29 inches, the last row of blades must be considerably higher than the preceding row to handle the large increase in specific volume of the steam passing to the exhaust. Again, as the stress in a disk due to the blades is proportional to the weight of the blade, the longer the blade and the higher the blade speeds, the greater the necessity for a construction to properly care for the stresses due to centrifugal force; and as the last one or two rows in the reaction turbine can be secured to a through disk, this design lends itself to a turbine of

maximum output, because (1) the rows immediately preceding the last rows of blades handle steam of considerably less specific volume, and (2) because in the reaction turbine a design with through disks supporting the last row or two of revolving blades can be made with such through disk construction, which, as shown in Appendix II, gives the maximum strength.

If the low-pressure portions are made double-flow, as is common practice with the reaction turbine, the maximum capacity obtainable is, of course, double the capacity of a single-flow machine. The facility with which reaction turbines are made double-flow, therefore, allows a maximum output of at least double the capacity obtainable in a design of Rateau or Curtis machines with equal blade speeds and equivalent operating conditions, and with equal reliability in service.

ECONOMY.

In order to compare the efficiencies which can be obtained with the Curtis, Rateau, and Parsons machines, reference is made to Figs. 10 to 16 inclusive, and to the consideration that the maximum efficiency for certain blade speeds in any type of turbine is dependent on (*a*) design of the blade elements, (*b*) the relative ratio of the velocity of the blades to the velocity of the steam, (*c*) the capacity of the turbine, and (*d*) the operating conditions.

Let S_b = mean blade speed,

Let S_s = mean steam speed,

Let E = blade efficiency.

If steam is admitted to a wheel with one row of impulse blades (Fig. 10), at a certain speed, S_s, and the blades are revolved at different speeds, S_b, theoretically, the efficiency is at a maximum for a certain blade speed given by the ratio,

$$\frac{S_b}{S_s} = \frac{\text{mean blade speed}}{\text{mean steam speed}} = \frac{1}{2}$$

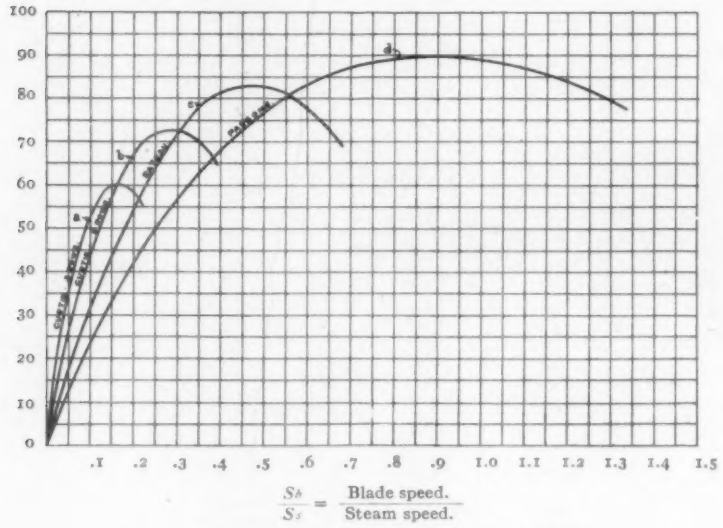
For any other ratios of $\frac{S_b}{S_s}$ the efficiency will be smaller, becoming zero when S_b = zero and when $S_b = S_s$.

The actual maximum efficiency and the ratio $\frac{S_b}{S_s}$ at which it is obtained depend mainly on the angles of the blades and

the frictional losses in the machine. Curve *c*, Fig. 50, represents a fair average of test results actually obtained in well-proportioned Rateau blading, the maximum efficiency being 82½ per cent. for $\frac{S_b}{S_s} = .47$ approximately.

For impulse wheels with two rows of moving blades the maximum efficiency is obtained for $\frac{S_b}{S_s} = .28$ approximately,

FIG. 50.



Efficiency curve. Parsons, Rateau, and Curtis wheels.

as shown on curve *b*, Fig. 50, such maximum efficiency being 72½ per cent.

For impulse wheels with three, four, or five rows of blades the maximum efficiency is obtained for $\frac{S_b}{S_s}$ less than $\frac{1}{6}$, $\frac{1}{8}$, and $\frac{1}{10}$ respectively. Of these, however, only the impulse wheel with three rows of blades is of practical importance, the actual efficiencies obtainable being given by curve *a*, Fig. 50, showing a maximum efficiency of 60 per cent. for $\frac{S_b}{S_s} = .17$ approximately. The efficiency of impulse wheels with more than three rows of moving blades is less, and they are therefore not

used except in cases where efficiency becomes a secondary matter.

For reaction turbines with multiple stages properly proportioned, and with relatively large capacities, the maximum efficiency is obtained for $\frac{S_b}{S_s} = .9$ approximately, at which the efficiency obtained on test has reached 90 per cent., with corresponding reductions when greater or less values of $\frac{S_b}{S_s}$ are used, as given by curve *d*, Fig. 50. The total pressure drop with the best efficiency obtainable must have: one wheel with three rows of blades, maximum efficiency 60 per cent.; or three wheels with two rows of blades, maximum efficiency 72½ per cent.; or twelve wheels with one row of blades, maximum efficiency 82½ per cent.; or forty-eight rows of reaction blades with a maximum efficiency 90 per cent.

From a comparison of these efficiency curves it is evident that the reaction blading is most desirable for the low-pressure portions of turbines where the blade heights become suitable for maximum efficiency, due to the reduction in the percentage of leakage loss, which vitiates the efficiency of the blade in proportion to such loss, and consequently becomes greater as the height of the blade becomes less. With, therefore, a blade clearance of ten-thousandths of an inch in the low-pressure portion of a reaction turbine with blades ten inches in length, the loss would be approximately four-tenths of one per cent. If, however, the blades were one inch in length, the loss would be approximately four per cent.; and as the capacity of the turbine diminished, requiring smaller blade heights, the leakage per cent. would have sufficient vitiating effect on the economy to warrant the introduction (in place of the reaction blading in the high-pressure stages) of a Rateau or Curtis element to get equal efficiency and the large initial drop in pressure which is desirable for mechanical reasons, given elsewhere in this paper. On the other hand, where the volume of steam, and consequently the capacity of the turbine, becomes great, on the score of efficiency, the impulse elements in the high-pressure stages can be dispensed with to advantage, because the reaction blading gives, under such conditions, reaction blade proportions for maximum efficiency. Such a condition has already been discussed in comparing the relative merits of designs for a 25,000-kilowatt machine.

The frictional resistance due to the revolving parts would undoubtedly favor the drum construction or reaction turbine, because the surface exposed in an equivalent design becomes less than in equivalent Curtis and Rateau machines.

The losses are, in any event, a small proportion of the total output of the machine, especially in high capacities, and the comparison of the advantages of the different types in this respect may be eliminated.

The improvement in economy due to the development of turbo-generator units up to 1906, of turbines built in this country, is indicated in Table I.

The most important tests obtained in the last five years on the complete expansion turbine, together with the authority for such tests, are given in Table II.

The efficiency of the turbines as shown in the tables is the ratio of the

$$\frac{\text{Actual useful work done by the turbine.}}{\text{The mechanical equivalent of the heat drop under the operating conditions, due to adiabatic expansion.}}$$

This ratio is commonly known as the Rankine-cycle efficiency. With turbo-generators this efficiency is generally stated by taking the actual energy output at the switchboard in kilowatts, as the numerator of the fraction expressed above, and is consequently less in value than the actual efficiency of the turbine itself, because the efficiency of the generator is less than unity.

When comparing the performance of turbines, the Rankine-cycle efficiency is a more correct basis than the water rates obtained on tests, because if the operating conditions are not similar the comparison of water rates is an unfair one, unless proper correction factors are applied.

Turbines are generally designed for given operating conditions, involving (*a*) quality of steam (superheat), (*b*) pressure, and (*c*) vacuum, and the correction for the change in these operating conditions as applied to a given machine must be taken into account when a comparison of the steam consumption of different machines is made.

Such corrections for steam consumptions should also be divided into two classes: (1) a comparison of turbines designed for different operating conditions, and (2) a comparison of turbines operating under conditions other than those for which they were designed.

For such corrections, standard steam conditions should be assumed to which the performance of all turbines may be reduced by applying proper correction factors.

Such standard conditions as now obtain in this country may be taken as follows:

For high-pressure turbines, 175 pounds pressure per square inch (gauge), 100° F., 28 inches vacuum (referred to 30-inch barometer);

For low-pressure turbines, 16 pounds pressure per square inch (absolute), 0° F. superheat, 28 inches vacuum, (referred to 30-inch barometer).

In Appendix III a list of correction factors is given for application to the general cases and operating conditions met in this country.

These correction factors are of great advantage to prospective purchasers of turbines, in order that they may more intelligently specify those operating conditions which are best suited to the economy of their plant.

FIELD OF APPLICATION OF THE TURBINE.

In the past five years the field of application of the turbine has been wonderfully increased, and the flexibility inherent in its construction has been developed by its adoption to: (1) non-condensing operations, (2) utilization of low-pressure steam, (3) reducing or bleeder turbines, and (4) mixed-pressure turbines.

In general, it may be stated that the distinguishing feature of these applications resolves itself into expansion of steam to and from atmospheric pressure.

Space will not permit a lengthy discussion of the various types of these special cases of the complete expansion turbine, except to say that conditions are arising to continually broaden the field of application of these special machines. Some general considerations of the designs of such machines obtain, however, which may be briefly stated as follows:

NON-CONDENSING TURBINES.

The non-condensing turbine may be made for any given condition, utilizing either the reaction or impulse machine with approximately the same efficiency, except where relatively large

TABLE I.

No.	Maker of turbine	Type	Date of test	Load KW.	R.P.M.	Steam pressure Lbs. Abs.	Super-heat	Vacuum referred to 29.92" barom-eter	Pounds of steam per KW.Hr.	Effi-ciency ratio	Reference
8	Westinghouse Machine Co.	Parsons	1902	1998	1200	170.1	41.56	26.91	19.10	58.0	Purchaser's Test, Hartford Elec. Lt. Co.
84	Westinghouse Machine Co.	Parsons	1905	5694	750	193.2	131.50	27.41	16.20	60.7	Purchaser's Test, Penn. T. & T. Co.
253	Westinghouse Machine Co.	Parsons	1907	9865	750	191.7	96.00	27.31	14.98	67.2	Electrical World, Jan. 29, 1908.
	General Electric Co.....	Curtis	1907	10186	720	190.7	147.00	29.47	12.90	62.1	Electrical World, Jan. 29, 1908.

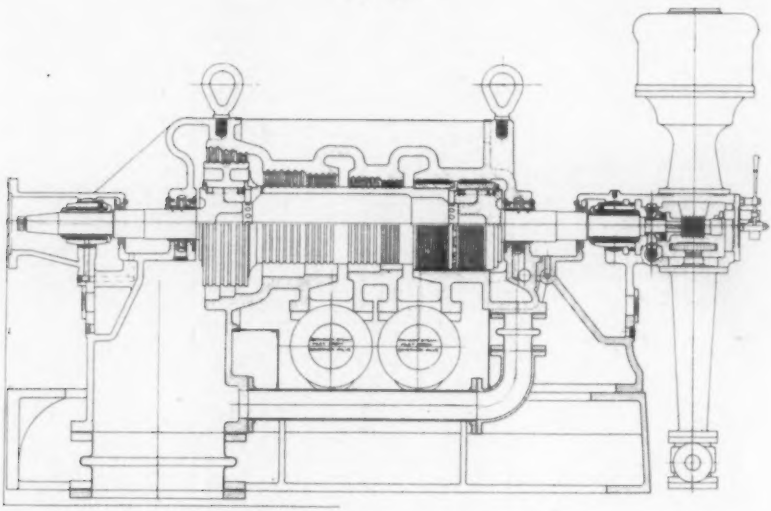
TABLE II.

No.	Maker of turbine	Type	Date of test	Load K.W.	R.P.M.	Steam pressure Lbs. Abs.	Super-heat	Vacuum referred to 29.92" barom-eter	Pounds of steam per KW.Hr.	Effi-ciency ratio	Reference
1	Erste Brunner M.F.G.....	Curtis-Parsons	1910	2128	1500	156.2	120.31	27.89	13.82	71.8	Periodische Mitteilungen.
2	Erste Brunner M.F.G.....	Curtis-Parsons	1910	6000	960	184.9	197.64	28.18	12.56	71.3	Zeit. d. V. D. Ing., 12/10/'10.
3	Erste Brunner M.F.G.....	Curtis-Parsons	1910	7442	960	192.0	205.51	28.18	12.625	70.3	Periodische Mitteilungen.
4	Westinghouse Machine Co.	Curtis-Parsons	1910	9173	1800	181.7	59.07	27.81	14.57	68.9	Trans. A. S. M. E., Vol. 32.
5	Erste Brunner M.F.G.....	Curtis-Parsons	1910	1416	1260	128.2	135.69	27.60	15.18	68.8	Periodische Mitteilungen.
6	Allis-Chalmers.....	Parsons	1908	4300	1800	186.4	107.97	27.96	14.02	68.4	Sibley Jour. of Eng. 1/11/'
7	Richardson & Westgarth..	Parsons	1910	6257	1200	203.7	176.00	29.10	11.90	68.4	Electrician, Vol. 66, p. 862, 1911.
8	General Electric Co.....	Curtis	1912	12460	720	207.5	191.00	27.52	13.63	68.2	Jour. A. S. M. E., Aug. '12, p. 1169.
9	Brown-Boveri & Cie.....	Curtis-Parsons	1911	3053	1360	150.2	146.40	29.00	13.01	68.0	Dinglers P. J., 6/17/'11.
10	Brown-Boveri & Cie.....	Curtis-Parsons	1911	1750	1500	176.4	214.50	27.08	14.23	67.5	Zeit. f. d. G. Turb., 5/30/'11.

11	James Howden & Son.....	Zoelly	1909	6383	1000	202.7	136.98	27.33	14.305	67.5	Engineer, London, 10/29/'09.
12	M. A. N.....	Zoelly	1910	1400	3000	180.7	180.53	27.40	14.21	67.4	Zeit. d. V. D. Ing., 12/10/'10.
13	Richardson & Westgarth..	Parsons	1910	5600	1200	203.7	166.00	29.12	12.10	67.3	Electrician, Vol. 66, p. 862, 1911.
14	Westinghouse Machine Co.	Curtis-Parsons	1906	9830	750	192.2	96.43	27.22	15.15	67.0	Trans. A. S. M. E., Vol. 32.
15	British Westinghouse.....	Curtis-Rateau	1911	5066	1500	190.2	174.31	28.68	13.00	67.0	Electrical Review, 6/23/'11.
16	Brown-Boveri & Cie.....	Curtis-Parsons	1910	3764	1500	161.2	196.78	28.77	13.04	66.8	Zeit. f. d. G. Turb., 5/30/'11.
17	Escher Wyss & Co.....	Zoelly	1910	2052	3000	193.9	205.70	28.39	13.04	66.6	Zeit. f. d. G. Turb., 2/20/'11.
18	General Electric Co.....	Curtis	1907	7526	720	184.4	134.00	28.65	13.732	66.6	Jour. A. S. M. E., Aug. '12, p. 1169.
19	British-Thomson-Houston	Curtis	1911	2987	1500	154.7	144.07	26.75	15.96	66.5	Engineering, 10/20/'11.
20	Bergmann.....	Curtis-Rateau	1909	1545	1500	188.5	204.04	28.59	12.97	66.4	Zeit. d. V. D. Ing., 12/10/'10.
21	Westinghouse Machine Co.	Parsons	1907	9870	750	191.7	95.00	27.25	15.00	66.3	Zeit. d. V. D. Ing., 1907, p. 1782.
22	General Electric Co.....	Curtis	1907	12000	750	200.0	125.00	28.00	14.22	66.2	Jour. A. S. M. E., Aug. '12, p. 1169.
23	Oerlikon.....	Rateau	1911	3166	1500	213.9	275.42	29.25	11.44	66.1	Engineering, 10/20/'10.
24	General Electric Co.....	Curtis	1911	6500	1800	180.0	100.00	28.00	14.78	66.1	Jour. A. S. M. E., Aug. '12, p. 1169.
25	Escher Wyss & Co.....	Zoelly	1911	5118	1000	133.7	199.48	27.55	15.18	65.7	Dinglers P. J., 7/15/'11.
26	Bergmann.....	Curtis-Rateau	1910	2477	1500	140.0	168.91	28.81	13.93	65.6	Elict. Zeit., 4/20/'11.
27	Brown-Boveri & Cie.....	Parsons	1903	3500	1360	156.4	137.20	28.84	13.71	65.6	Zeit. d. V. D. Ing., 12/10/'10.
28	Westinghouse Machine Co.	Curtis-Parsons	1909	11466	750	191.7	105.65	28.07	14.45	65.5	Trans. A. S. M. E., Vol. 32.
29	Escher Wyss & Co.....	Zoelly	1910	4189	1000	179.7	183.98	28.66	13.30	65.5	Zeit. f. d. G. Turb., 2/20/'11.
30	Richardson & Westgarth..	Parsons	1910	4256	1200	206.7	162.00	29.19	12.40	65.1	Electrician, Vol. 66, p. 862, 1911.
31	British Westinghouse.....	Curtis-Rateau	1911	2930	1500	210.2	187.90	28.18	13.72	64.9	Electrical Review, 4/28/'11.
32	A. E. G.....	Curtis-Rateau	1908	4239	1500	188.3	285.13	29.11	11.97	64.9	Stodola, 4th ed., p. 404.
33	Escher Wyss & Co.....	Zoelly	1911	3540	1500	155.1	107.86	28.21	15.07	64.8	Dinglers P. J., 7/15/'11.
34	F. Ringhoffer.....	Zoelly	1908	3000	1000	170.7	101.18	27.60	15.52	64.8	Zeit. d. V. D. Ing., 12/10/'10.
35	Brown-Boveri & Cie.....	Parsons	1907	3522	1360	156.9	136.00	28.945	13.70	64.8	Zeit. d. V. D. Ing., 1908, p. 516.
36	Els. Masch. Fabr.....	Zoelly	1910	3500	1500	177.7	142.00	28.435	14.07	64.8	Zeit. d. V. D. Ing., 1910, p. 1500.
37	M. A. N.....	Zoelly	1910	1250	3000	182.1	207.89	28.82	13.09	64.4	Zeit. d. V. D. Ing., 12/10/'10.
38	Brown-Boveri & Cie.....	Parsons	1910	3000	1360	165.0	258.91	27.02	14.75	64.3	Die Turbine, 6/20/'11.
39	C. A. Parsons & Co.....	Parsons	1907	5164	1200	214.3	121.26	28.95	13.18	64.3	Stodola, 4th ed., p. 439.
40	British Westinghouse.....	Curtis-Rateau	1911	3645	1500	208.3	180.00	27.78	14.03	64.3	Electrical Eng'r, Vol. 47, p. 461, '11.
41	A. E. G.....	Curtis-Rateau	1906	3766	1500	185.2	247.00	28.78	12.80	64.2	Zeit. d. V. D. Ing., 1907, p. 386.
42	Escher Wyss & Co.....	Zoelly	1910	1641	3000	221.0	281.63	27.91	13.08	64.1	Zeit. f. d. G. Turb., 2/20/'11.

capacities are demanded, in which case the reaction turbine would have the advantage in efficiency. Since a non-condensing operation would require approximately twice the amount of steam for a given output as would be necessary with a complete expansion turbine, opportunity would be afforded for better proportioning of the reaction blading to give maximum efficiency, and, due to the incomplete expansion, a relatively short spindle would result on account of a smaller number of rows of

FIG. 51.



Longitudinal section, 15 N.C., 3600 revolutions per minute, single-flow high-pressure turbine with Kingsbury thrust-bearing.

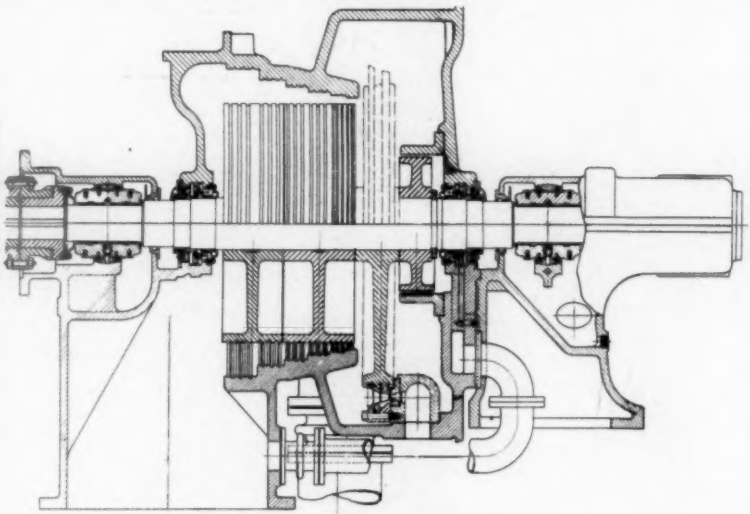
blades being required to absorb less than half of the total energy drop occurring in a complete expansion machine. A design of such a turbine is illustrated in Fig. 51.

LOW-PRESSURE TURBINES.

In a low-pressure turbine design, the reaction elements again lend themselves admirably to the efficient extraction of the energy of low-pressure steam, because, for a given output, the blade proportions of the low-pressure turbine would be practically twice the capacity of those required in a single expansion turbine, resulting, as in non-condensing operation, in blade proportions of maximum efficiency, a short, simple construction of the spindle and cylinder, and (with moderate capacity) the

elimination of balancing pistons by resorting to the double-flow construction. The same arguments for simplicity would, of course, apply to impulse turbines, but the fact that reaction blading is, in general, best adaptable to the low-pressure portions of any turbine should be a distinct advantage in favor of such a machine in low-pressure work. Figs. 52 and 53 indicate single- and double-flow low-pressure machines as built by The Westinghouse Machine Company.

FIG. 52.



Low-pressure single-flow turbine.

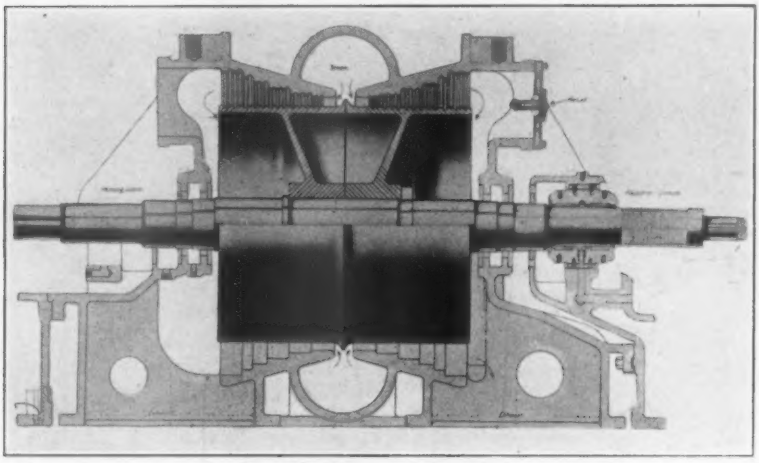
REDUCING OR BLEEDER TURBINES.

Where it is desirable to utilize steam at about atmospheric pressure for heating or industrial purposes, the turbine lends itself admirably to fulfil such a condition. It is extremely simple to bleed steam out of the turbine, at any particular pressure, in quantity proportional to the amount of flow through the turbine. Suitable automatic valves may be applied to the bleeder exhaust of the turbine to maintain (irrespective of the load the turbine may carry) that quantity of steam required to maintain a constant pressure in the bleeder line.

The conditions having been determined as to the amount of steam to be supplied from the turbine, the proportions of the elements beyond the bleeder valve are made to utilize the steam

remaining under the operating conditions imposed, thus extracting the maximum amount of energy from the complete expansion of the steam required for generating power, and giving at the same time a constant steam supply at a given pressure (usually about 15 to 20 pounds absolute) for heating or industrial purposes. Likewise, with suitable valve arrangements, steam at relatively low pressures, say 15 pounds absolute, can be bled into the low-pressure portion of the turbine, and the energy from the expansion of such steam to a high vacuum may be utilized in the low-pressure portion of a bleeder turbine for the

FIG. 53.



Low-pressure double-flow turbine.

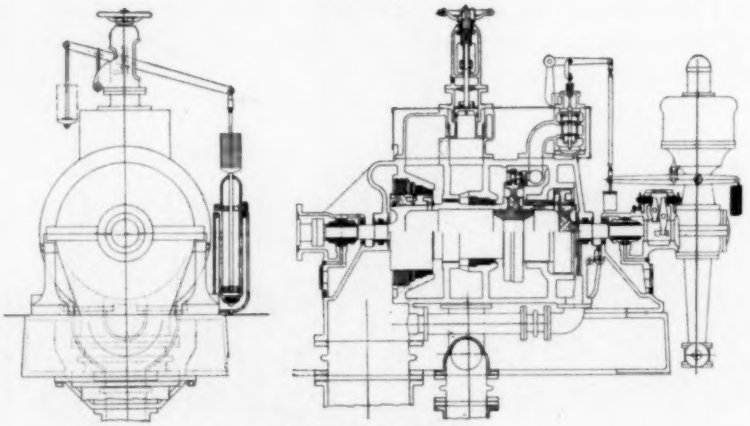
development of power. The bleeder valves and the initial steam valve, in the high-pressure portion of the turbine, may be governor-controlled and make, therefore, a purely automatic machine, which will take care of variable operating conditions by the governor control. An illustration of such a machine is shown in Fig. 54, where the high-pressure portion is designed with an impulse wheel and the low-pressure portion with reaction blading.

MIXED-PRESSURE TURBINES.

The mixed-pressure turbine is really a modification of conditions requiring a low-pressure turbine. Suppose a source of

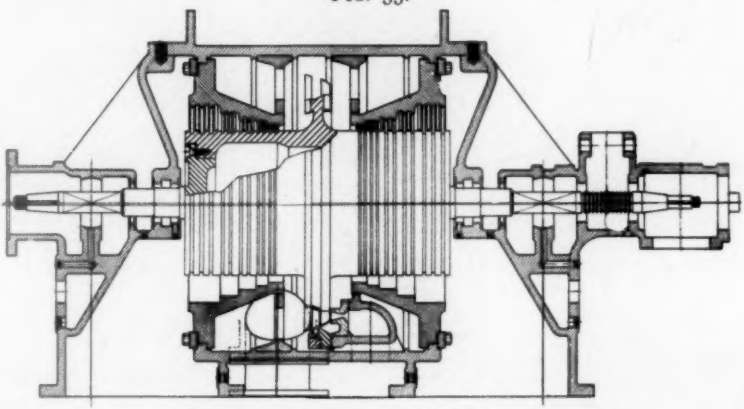
low-pressure steam being available from which it is desirable to extract the energy in the development of power, and where, at certain times in the operation, sufficient low-pressure steam is not available to generate the amount of power required: To

FIG. 54.



Bleeder turbine assembly.

FIG. 55.

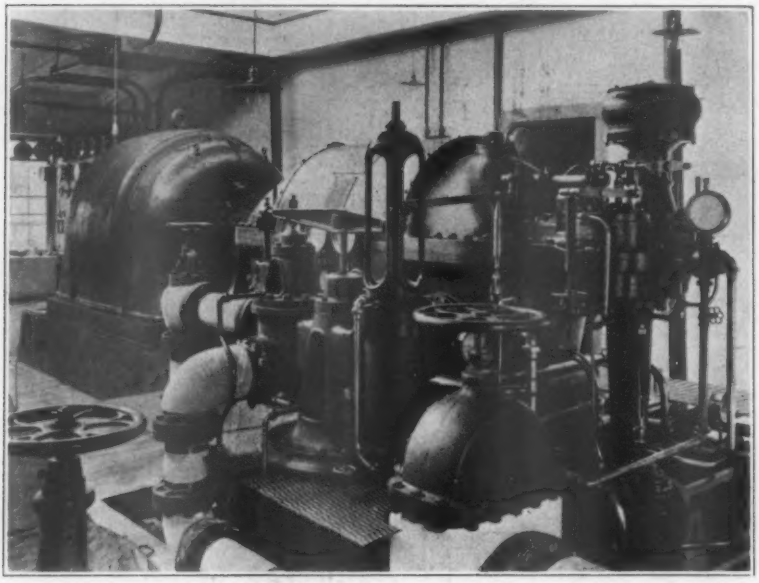


Low-pressure turbine with live steam valve.

suit this condition, a low-pressure turbine is supplemented by a high-pressure element which can utilize steam at high pressure through complete expansion. When sufficient low-pressure steam is available to furnish the required power, the high-pressure steam is cut off by the governor or by other means, and when the low-pressure steam is not sufficient for the power required,

the governor of the turbine admits steam to the high-pressure element to supplement the low-pressure supply for the development of the power required. This same arrangement can be accomplished with the low-pressure turbine by applying a high-pressure valve admitting steam into the low-pressure line direct. Figs. 55 and 56 illustrate machines of this construction, and the desirability of either type depends entirely on the operating conditions imposed.

FIG. 56.



Low-pressure turbine with live steam valve, installed at Peace Dale Manufacturing Company, Peace Dale, R. I.

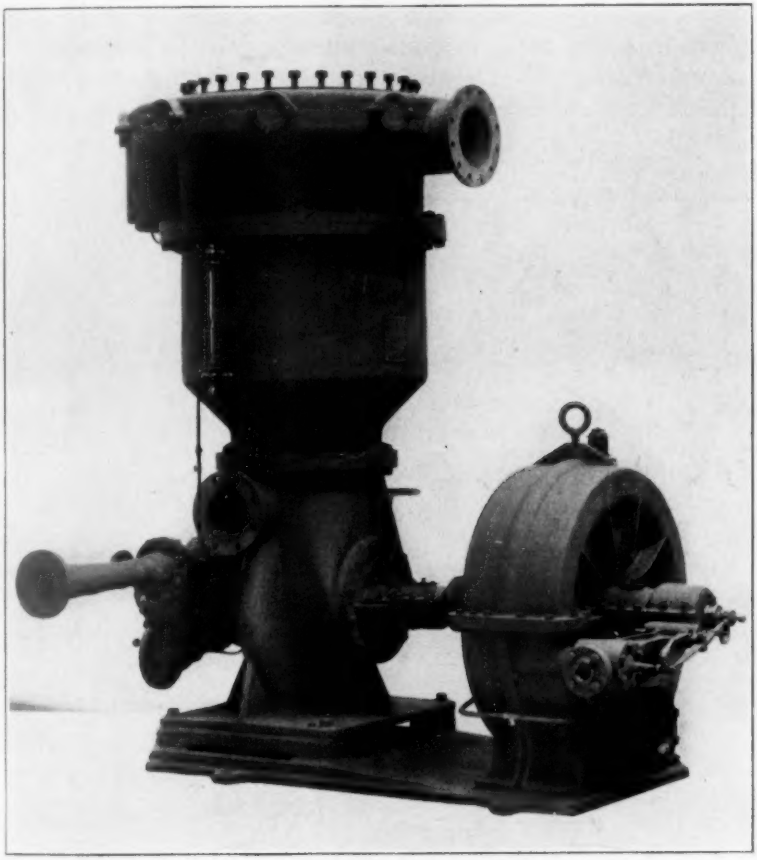
RECENT MISCELLANEOUS TURBINE APPLICATIONS.

Due to the recent development of small turbines of relatively low rotative speeds that have recently come into quite extended use for driving auxiliaries in power plants and for other applications, apparatus which formerly was operated by reciprocating means has been developed for rotary drive with marked reduction in the cost, weight, space occupied, and efficiency obtained.

Perhaps the best example of this development has been the

commercial introduction of the Westinghouse-Leblanc condenser, which, by the introduction of a rotary vacuum pump, permits the driving of the condenser circulating and air pumps by direct connection to a small turbine unit, as illustrated in Fig. 57.

FIG. 57.



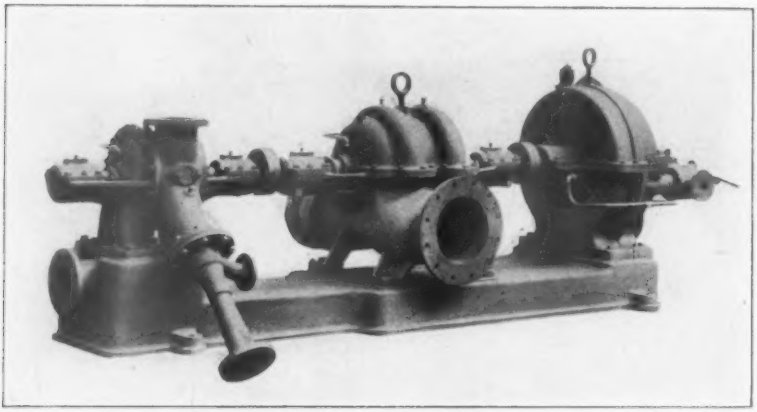
Turbine-driven type E high-speed condenser.

The application of the small turbine to the field of centrifugal pumps is rapidly replacing the reciprocating engine, the advantages of the turbine being due to the fact that for low lift pumps and high-pressure pumps the speed for the best design is beyond that suitable for direct connection to a reciprocating engine.

Fig. 58 is an application of the small turbine to a centrifugal circulating and Leblanc air pump for surface condensers. Fig. 59 illustrates a boiler feed centrifugal pump direct connected to a small Westinghouse turbine. Similarly, the small turbine is admirably adapted to the driving of centrifugal blowers, an example of which is illustrated in Fig. 60.

As auxiliary apparatus for large power stations, or in places where it is important to reduce attendance to a minimum and where reliability is essential, the small direct-current turbo-generator unit is now generally accepted in place of the recipro-

FIG. 58.



Air and circulating pump unit for 2000 square feet surface condenser, built for Louisville & Nashville Railway Company.

cating engine, direct-connected or belt-driven apparatus, principally on account of its reduced size and cost, and the many advantages incident to rotary apparatus. Fig. 61 represents several sizes of these machines, from 1 kilowatt up, as manufactured by The Westinghouse Machine Company, both in direct- and alternating-current sets.

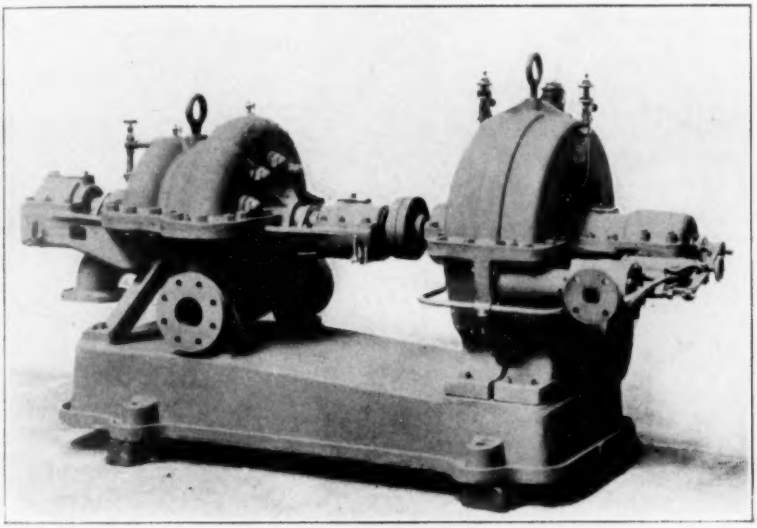
APPLICATION TO MARINE SERVICE.

The application of the turbine to marine propulsion is perhaps the broadest single field for the utilization of maximum horsepower output. Until within the last few years this field was limited to approximately 5 per cent. of the total merchant

marine vessels, on account of the difficulty of correlating the high speed of the turbine and the relatively low speed of the ship's propeller.

It has been, of course, possible to apply turbines to the slower speed ships, but it has not been practicable to do so, because there would have been no saving in weight, space, or economy over the reciprocating engine, since the turbine is essentially a machine of relatively high rotative speeds for efficient

FIG. 59.



Small turbine driving boiler-feed pump.

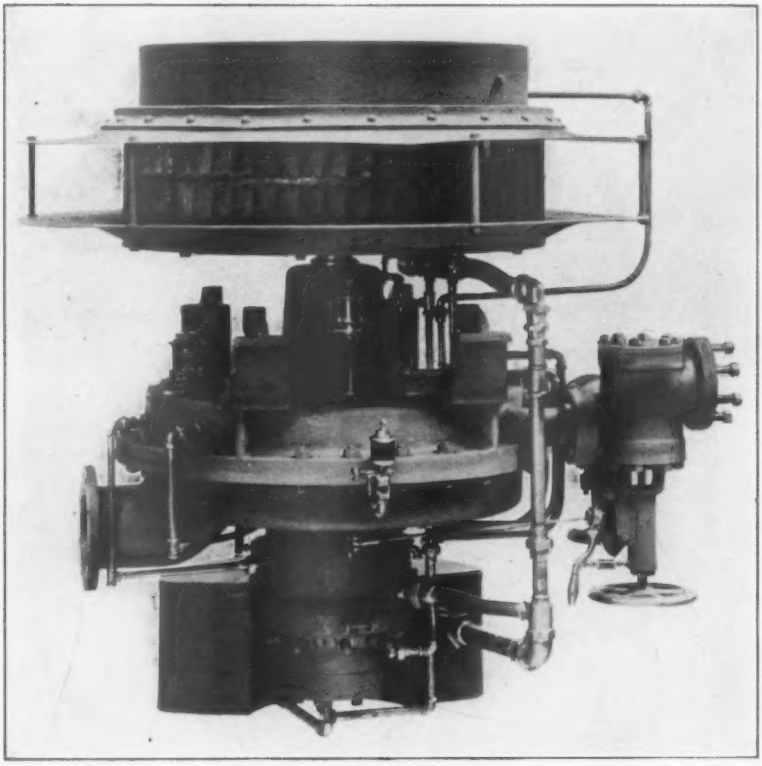
operation, while the screw propeller requires relatively low speed of rotation.

Recognizing the possibilities of the steam turbine for marine propulsion, Mr. George Westinghouse, in 1903, commissioned the late Rear Admiral George W. Melville, Ex-Engineer-in-Chief of the United States Navy, and Mr. John H. Macalpine, Consulting Engineer, to make an impartial investigation and report on the status of the marine steam turbine.

This report, a number of copies of which were printed for private circulation in May, 1904, did not indicate that the reciprocating engine would be immediately superseded by the

steam turbine, as it was then being applied to marine propulsion, but concluded with the statement that: "If one could devise a means for reconciling in a practical manner the necessarily high speed of the turbine with the comparatively low rate of revolution required by an efficient propeller, the problem would be solved and the turbine would practically wipe out the recipro-

FIG. 60.



06 V.N.C turbine with 39-inch 25,000 cubic foot Navy type blower.

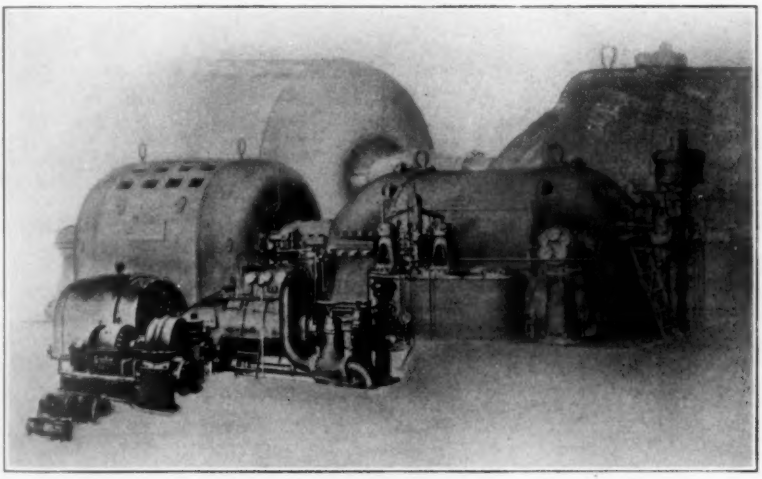
cating engine for the propulsion of ships. The solution of this problem would be a stroke of great genius."

Acting on this suggestion, Mr. Westinghouse caused designs to be made for a reduction gear for large power transmission, which was constructed and tested in the works of The Westinghouse Machine Company at East Pittsburgh, after designs

of Messrs. Melville and Macalpine embodying a floating frame carrying the pinion, which had been shown mathematically to be necessary to the successful operation of high-speed gearing transmitting large powers.

This experimental gear transmitted under test 6800 horsepower with a pinion speed of 1500 revolutions per minute and a gear speed of 300 revolutions per minute. These tests demonstrated conclusively that the floating frame would insure correct alignment of the gear teeth, which is absolutely essential to the transmission of large powers. It was believed that this par-

FIG. 61.



1-kilowatt to 10,000-kilowatt turbines.

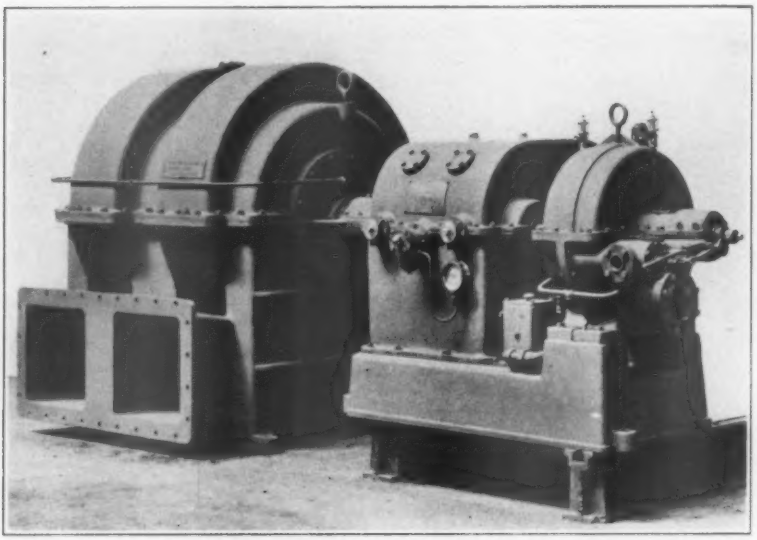
ticular design was more rigid than desirable, because the connection between the floating frame and the casing was a metallic one, and in consequence noise and vibration were not eliminated to the degree that it was believed to be possible.

As a substitute, therefore, for the Melville-Macalpine design, Mr. Westinghouse devised a hydraulically supported pinion frame having a degree of flexibility in itself, and which was supported on the main frame by oil in the hydraulic cylinders in the floating frame. This construction also allowed vertical movements of the pinion and floating frame, which were impossible in the Melville-Macalpine design.

A test on a large scale of the Westinghouse floating frame demonstrated that this accomplished all the objects of the original inventors, and, by reason of the absence of metallic connection between the pinion frame and the casing, the noise and vibration incident to the operation of the gear were almost wholly eliminated.

The tests on this large experimental gear aroused great interest in naval and merchant marine circles, and resulted in the

FIG. 63.

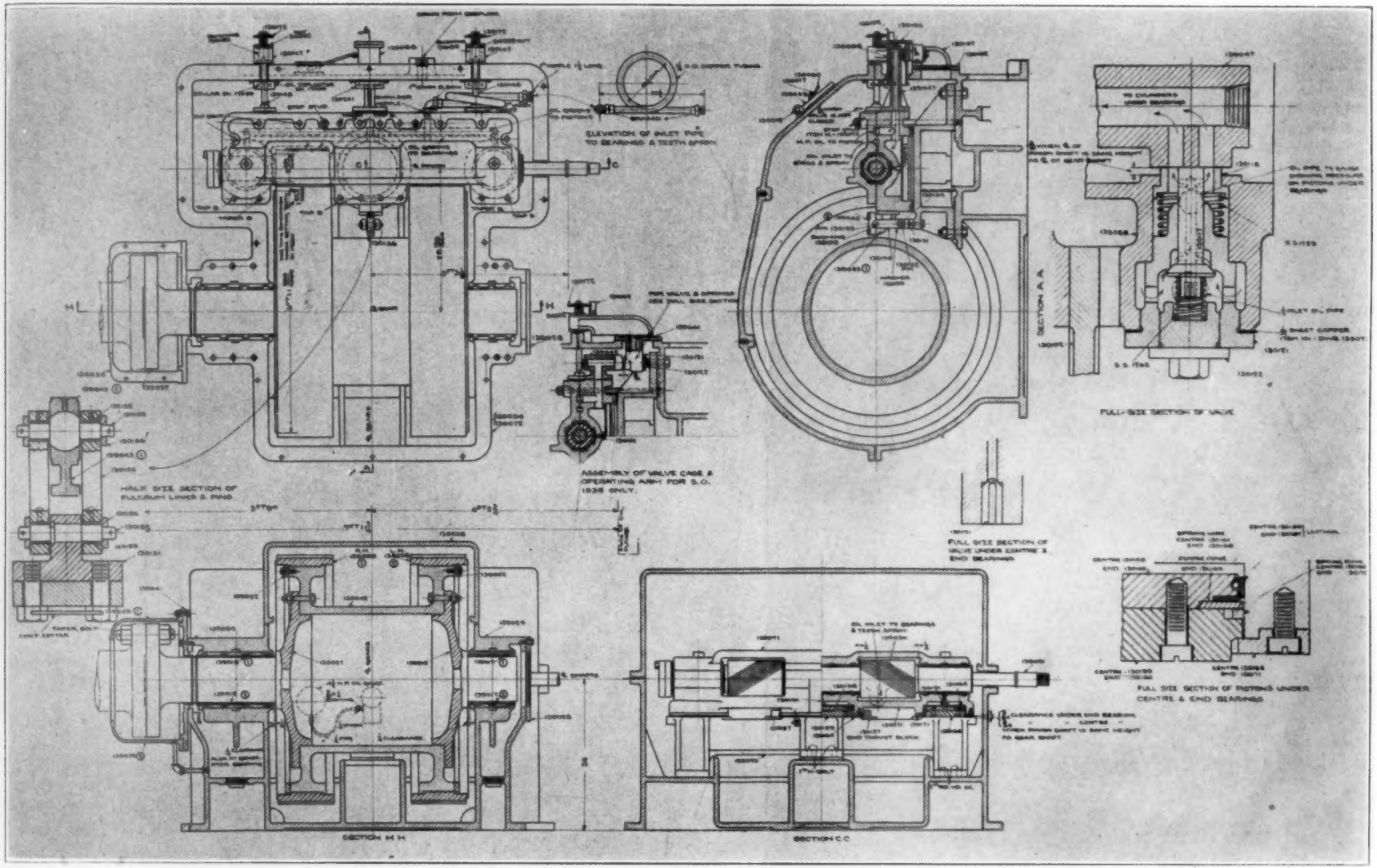


25,000 G.P.M. circulating pump, reduction gear and turbine drive. Built for Edison Electric Illuminating Company, Brooklyn, N. Y.

application of turbine gearing sets of 3600 horsepower each to the twin screw U. S. S. *Neptune*, and the general application of turbine gearing to the larger sizes of direct-current generators, centrifugal pumps, rolling-mill machinery, etc. A complete technical description of the experimental reduction gear and machinery in the U. S. S. *Neptune* may be found in London *Engineering* of September 17, 1909, and November 17, 1911, respectively.

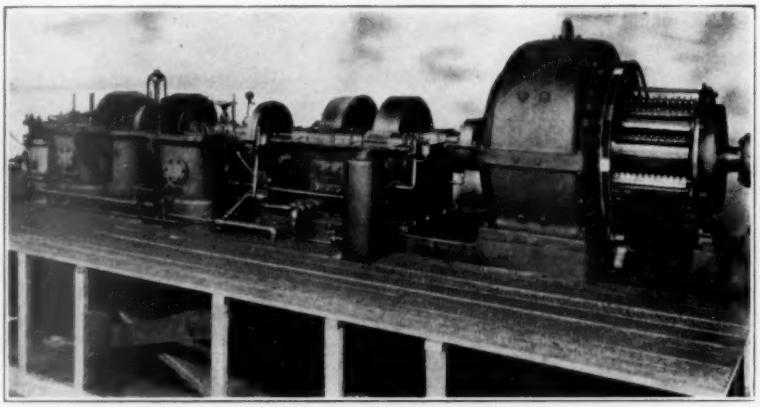
Twenty-one sets of the Westinghouse turbine reduction gearing have been constructed and installed by The Westinghouse Machine Company with eminently satisfactory results in opera-

FIG. 62.


ELEVATION OF INLET PIPE TO BEARINGS & TEETH SPRAY
ASSEMBLY OF VALVE CASE & OPERATING ARM FOR S.O. 1835 ONLY.
SECTION A A
FULL-SIZE SECTION OF VALVE
HALF SIZE SECTION OF FULCRUM LINER & PINS
FULL SIZE SECTION OF VALVE UNDER CENTRE & END BEARINGS
FULL SIZE SECTION OF PISTONS UNDER CENTRE & END BEARINGS
SECTION H H
SECTION C C

tion. A recent report made of the installations with direct-current generators ranging from 1000 to 2000 horsepower transmission gives the interesting figures shown in Table III, together with the statement that no appreciable wear is evident on the teeth of any of these gears. The distinctive feature of the Westinghouse gears which are of the double helicoidal type is the flexible or self-aligning quality of the pinion shaft, which, with its frame and bearings, is hydraulically supported in such a manner as to equalize and distribute the tooth pressure evenly, resulting in smooth and quiet running without the necessity of

FIG. 64.



500-kilowatt turbine, 1000 horsepower reduction gear and D.C. generator (covers removed) (turbine 3600 revolutions per minute, gear 720 revolutions per minute). Built for the Commonwealth Steel Company, Granite City, Ill.

grinding the teeth or of exercising that extreme care and accuracy in alignment of the pinion bearings which are so essential in a gear of large size. Fig. 62 illustrates the general construction of one of these gears as applied to direct-current generators where the speed of rotation is in one direction only. Fig. 63 illustrates the application of reduction gearing to turbine-driven centrifugal pumps, and Fig. 64 its application to the operation of direct-current generators. Fig. 65 illustrates the construction of the most recent design of marine reduction gearing where the rotation of the pinion is required for either direction. In these figures the construction of the floating frame and its pistons is readily observed.

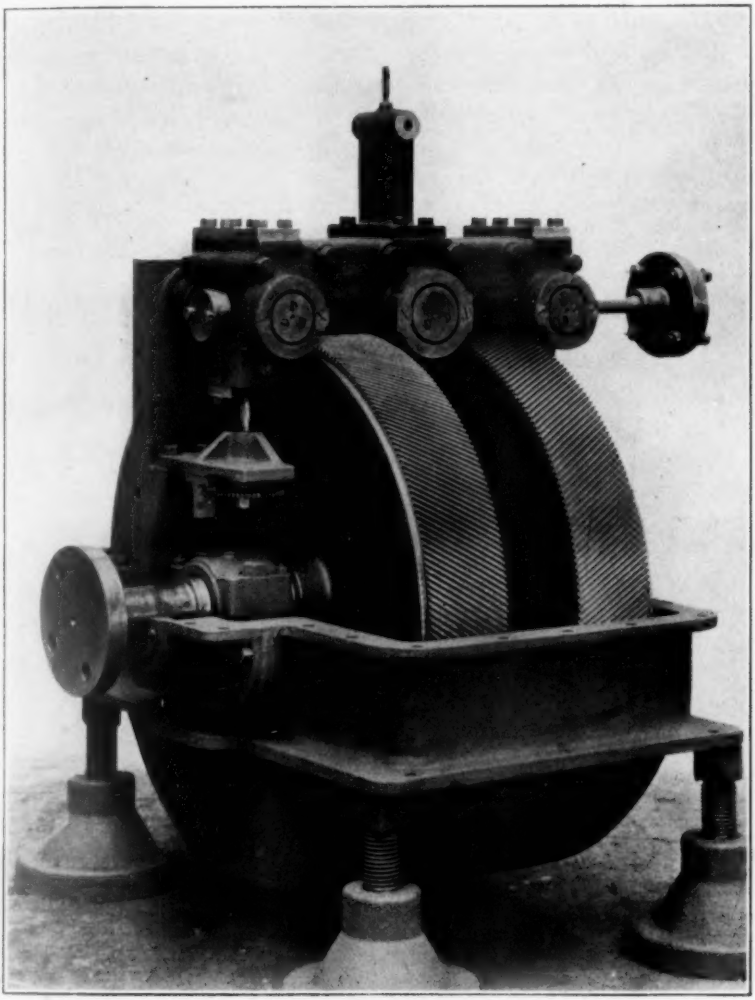
The supporting of the pinion frame hydraulically incidentally

TABLE III.

	Chrome Steel Works.	Commonwealth Steel Co.	Walpole Rubber Company.	San Diego E. L. & P. Co., Cal.	N. Y., N. H. & H. R. R.	Aluminum Co. of America.	Colorado Portland Cement Co.
Number of hours run..	4,500	7,500	6,220	6,132	4,166	2,000	8,500
Diameter of pinion....	5½	5½	5½	7	7	5½	7
Revolutions per minute pinion.....	3,600	3,600	3,600	3,600	3,600	3,600	3,600
Total number of revolutions.....	972,000,000	1,620,000,000	1,340,000,000	1,320,000,000	900,000,000	432,000,000	1,840,000,000
Horsepower maximum.	1,000	1,000	1,000	2,000	2,000	1,000	2,000
Horsepower per pinion, average.....	370	770	about 700	880	1,200	480	1,175
Gear ratio.....	1 to 5	1 to 5	1 to 5	1 to 7	1 to 7	1 to 5	1 to 7
Width of gear face	17.5″	17.5″	17.5″	22″	22″	17.5″	22″
Number of teeth per pinion.....	31	31	31	32	32	31	32
Pinion material.....	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.
Gear material.....	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.	Mild steel. .30 to .40 carbon.

gives a very accurate dynamometer, since the hydraulic pressure supporting the frame is proportional to the load carried; and with the knowledge of the speed of rotation, the area of the

FIG. 65.



Marine reduction gear. Part of cover removed.

pistons supporting the pinion frame, and the hydraulic pressure, the horsepower transmitted is readily computed without the aid of special or delicate instruments, or expert observers.

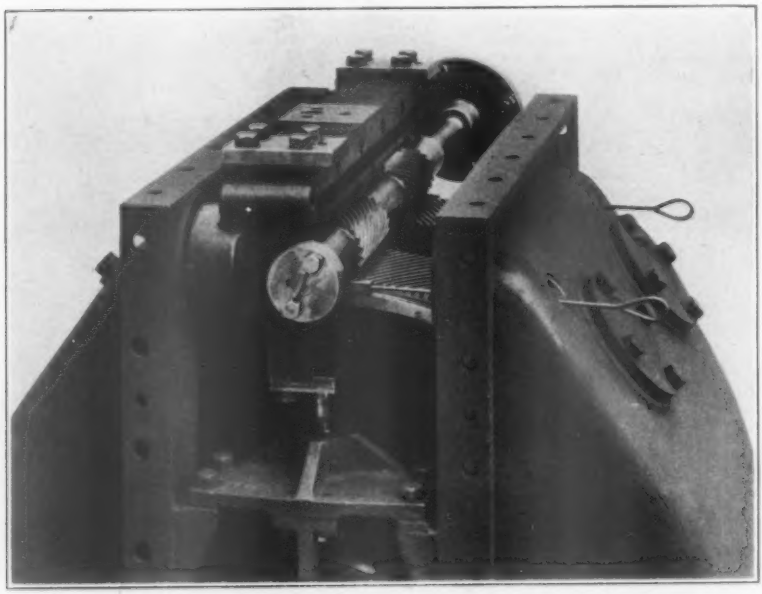
This dynamometer feature should be of great service in

marine work where it is very desirable to obtain the horsepower delivered to the propeller shaft.

The application of the turbine itself to marine work is a different kind of a problem than to driving electrical apparatus, for the reason that in the former case a variable speed is required, while in the latter case a constant speed is required.

In the majority of cases, after a ship is under way, the speed may be considered as constant. In naval vessels, however, it is generally desirable to have a cruising speed, approxi-

FIG. 65A.



Marine reduction gear. Showing floating frame and pistons.

mately one-half of the full speed. This involves a compromise in the turbine design to give relatively high economy for cruising at a propeller speed of approximately one-half that of full speed, and a power output of approximately one-eighth to one-tenth that required at full speed.

As has been pointed out previously in this paper, the efficiency of turbines increases with the power and decreases as the blade speed decreases, with the same pressure drop.

While the introduction of gearing very materially adds to the ease of design and construction of marine turbines and to

their increased economy, due to the high rotative speeds, and on account of the better blading proportions, yet both theory and practice require a very different blading for marine operation than for land service with constant speed, especially where cruising speeds in marine service are desirable.

Fig. 50 shows that the efficiency of any blading diminishes as the velocity ratio diminishes or increases, beyond a certain velocity ratio which gives maximum efficiency.

Irrespective, therefore, of the diminution in power at cruising speed, the fact that the speed of rotation of the turbine is reduced one-half would, with the same energy drop, result in a very marked decrease in efficiency. If, however, the turbine be over-bladed, a reduction in the speed of rotation over that obtaining at full power will still give a high efficiency,—and the widest range in this respect, as illustrated in Fig. 50, may be obtained with reaction blading rather than pure Curtis or pure Rateau elements.

If, however, a combination impulse reaction turbine is employed for marine service, and the blading proportions are properly relegated in the impulse and reaction sections, one to the other, the reduction in efficiency in either may be offset by an increase in efficiency in the other, and consequently a more uniform water rate or efficiency may be obtained over wide ranges of speed and power. Also, the remarks already made in connection with the advantages of the combination impulse reaction turbine for electric drive hold good for the application of the turbine to naval or merchant vessels, and for these reasons it is believed that this type will predominate in the future construction of marine installations.

Since the availability of the Westinghouse reduction gear to marine application has been demonstrated, a great deal of experimental work has been instituted and put in progress by Mr. Westinghouse to determine experimentally those features of turbine operation and design which are essential for high economy in the propulsion of naval vessels by means of a turbine and its reduction gearing. These experiments have progressed sufficiently far to warrant the statement made above in connection with the use of the Westinghouse impulse reaction turbine.

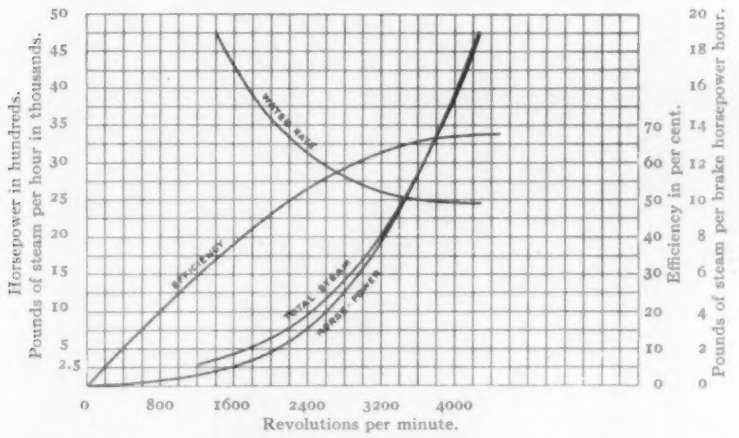
Fig. 66 illustrates tests made at variable speeds and powers

on a standard commercial Westinghouse impulse reaction turbine designed for turbo-generator work.

There can be no doubt that with a variation in the blading proportion of this machine suitable for marine work the efficiency and water rate curves can be materially flattened and bettered.

The author regrets that at this time he is not in a position to report more fully on what can be accomplished for the betterment of steam consumption in marine propulsion, but from the investigations now under way at the plant of The Westinghouse

FIG. 66.



Turbine No. 2190. Variable speed with nozzle control. Reduced to basis of 388 available B.T.U.

265 pounds absolute high pressure inlet, 60° F. superheat, 28.5 inches vacuum. Ratio of speed to power deduced from trials of *North Dakota*.

Machine Company and the development of the turbine and reduction gear as it has rapidly progressed, these will eventually eliminate the reciprocating engine from the field of marine propulsion, as the turbo-generator has effectually eliminated the reciprocating engine driven generator from power station use. As far as the investigations have now progressed it seems entirely practicable to reduce the economy of the reciprocating engines of the battleship *Delaware* 30 per cent. at full speed and 25 per cent. at cruising speed.

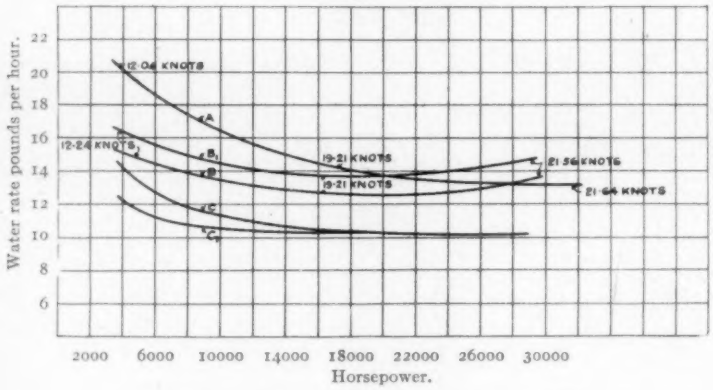
Fig. 67 illustrates a set of water rate curves of the main propelling machinery of a battleship.

Curve *A* represents the water rate based on shaft horse-

power obtained on the Government acceptance trials of the U. S. battleship *North Dakota,* equipped with Curtis turbines; Curve *B* the results based on the indicated horsepower of the trials of the U. S. battleship *Delaware,* equipped with reciprocating engines; and Curve *C* the results based on the shaft horsepower which could be obtained by the installation of Westinghouse turbines and reduction gears, in which the turbine efficiency is taken from the tests of a commercial Westinghouse impulse reaction turbine designed for turbo-generator work.

Curve C_1 in Fig. 67 represents the water rate which could

FIG. 67.



A . *North Dakota,* Curtis turbines, water rate per S.H.P.
B . *Delaware,* Reciprocating engines, water rate per I.H.P.
B_1. *Delaware,* water rate per equivalent S.H.P.
C . Westinghouse geared turbines, water rate per S.H.P.
C_1. Westinghouse twin-geared turbines, water rate per S.H.P.

be obtained with the use of two independent turbines geared to one propeller shaft, since it is obvious that at cruising speeds one of these turbines could develop the cruising power with better efficiency than if both were operated, or better than if one turbine alone drove through gearing the propeller shaft, for the reason that instead of developing, say, one-tenth of the full power, as would be necessary in a single turbine, one unit of the double turbine arrangement would develop one-fifth full power at cruising speed.

The geared turbine not only results in a very material reduction in the water rate, and consequently the coal consumption, of a ship, but other advantages lie in the saving which may

be effected in weight and space. The comparative figures for battleships of the *Delaware* and *Oklahoma* class indicate that the saving in the length of machinery space would amount to 23 per cent. for the former and 30 per cent. for the latter, while the saving in weight would amount to 20 and 21 per cent. respectively.

The application to the merchant marine indicates a saving in space of 40 per cent., a saving in weight of 50 per cent., and a reduction in steam consumption of 30 per cent.

With high-speed turbine and reduction gear installations, other advantages occur, as for instance in the method of control of the engines, which allows, by a simple reliable apparatus, the operation of the turbines from the bridge or any part of the ship.

The following is quoted from an article by Lieut. W. W. Smith, U. S. N., appearing in the August number of the *Journal of the American Society of Naval Engineers,* together with the illustrations, Plates I, II, and III:

"The turbines can be handled in the engine room or from the bridge, both operating stations being essentially the same. It makes no difference which station is used, as the turbines respond exactly the same to the bridge operator as they do to the engineer. Both use the same system, but control it from different places. There could be three or even more operating stations if desirable. In a battleship, for example, a third station could be located in the central station of the ship.

"Operating the turbines in the engine-room is much easier than with the usual types of turbine and engine-operating gear. There are two small levers, one for each turbine, which are operated by one man without difficulty. These two levers automatically control all of the necessary functions with a rapidity and precision which is impossible with manual control. The three principal functions controlled by the operating levers are reversing, regulation of speed, and nozzle control. The regulation of speed refers to the actual revolutions per minute the operator desires, and not the fixed opening of a valve, which only serves as the means for the operator to do this.

"Due to the action of the mechanism, reversals and changes of speed are very rapid, for when the operating lever is moved from one position to another the mechanism automatically opens

PLATE I.

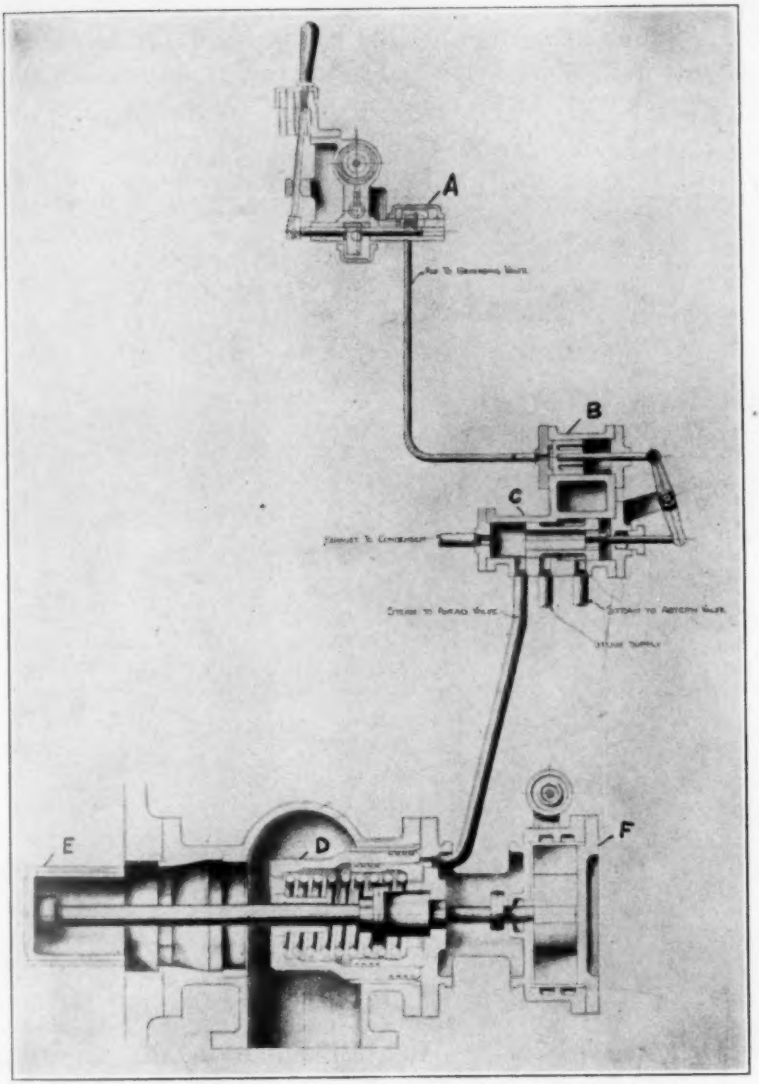


Diagram of Bridge-control Mechanism, Showing the Parts Used for Reversing.

A is the air-reverse valve of the control valve. *B* is the air-operating cylinder of the steam-reverse valve. *C* is the steam-reverse valve. *D*, is the turbine-operating or poppet valve. *E* is the nozzle control valve; *F*, its hydraulic-operating cylinder. *E* and *F* are not used in causing reversal.

wide or closes completely the turbine-inlet valve, which remains so until the exact speed for which the lever is set is attained. This feature of rapid response of the turbines is of importance, because it causes the ship to respond in the minimum of time. This action is always the same. It gives the ship uniform

PLATE II.

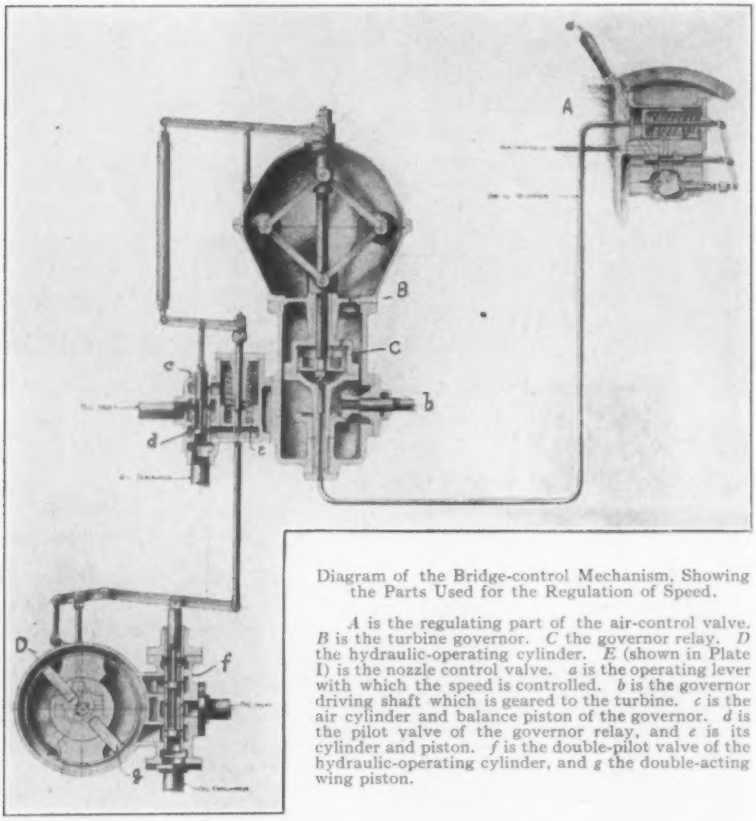


Diagram of the Bridge-control Mechanism, Showing the Parts Used for the Regulation of Speed.

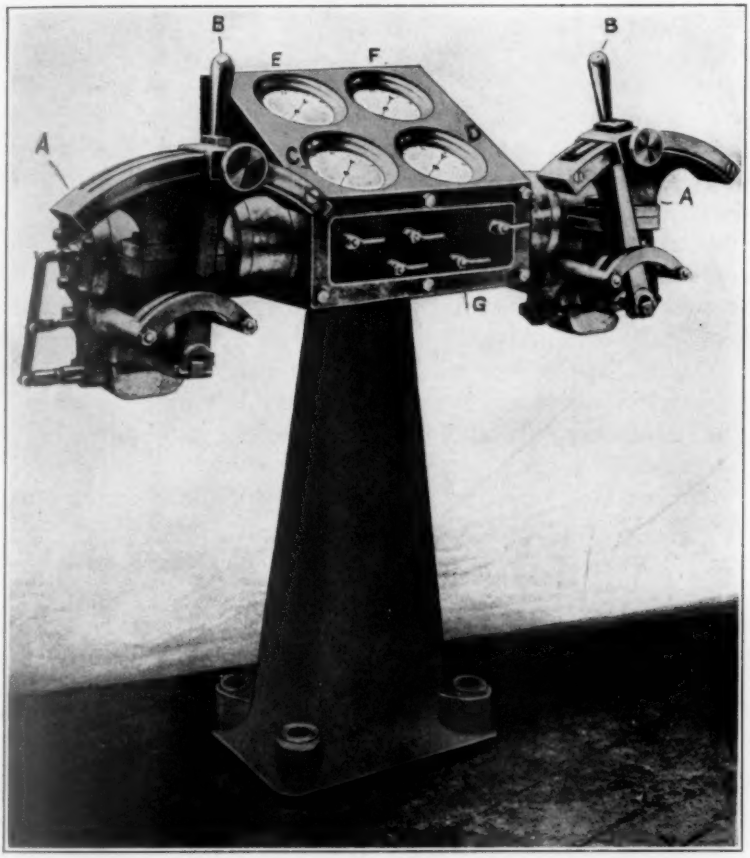
A is the regulating part of the air-control valve. *B* is the turbine governor. *C* the governor relay. *D* the hydraulic-operating cylinder. *E* (shown in Plate I) is the nozzle control valve. *a* is the operating lever with which the speed is controlled. *b* is the governor driving shaft which is geared to the turbine. *c* is the air cylinder and balance piston of the governor. *d* is the pilot valve of the governor relay, and *e* is its cylinder and piston. *f* is the double-pilot valve of the hydraulic-operating cylinder, and *g* the double-acting wing piston.

handling qualities, and, what is more important, it can be depended on in an emergency.

"When the operating lever is set for a certain speed the turbine comes up to this exact speed, and it is maintained automatically. This is true under all conditions, regardless of steam pressure, vacuum, propeller resistance, etc., provided

the speed is not too great,—*i.e.*, below the maximum possible under the condition. This feature makes the operation easy

PLATE III.



The Bridge Stand Showing the Air-control Valves A for Both Turbines.

Regulation of speed and reversal are controlled by the operating levers *B*. *C* is the main steam-pressure gauge. *D* the air-reservoir pressure. *E* and *F* are indicators showing the governor air pressure and the revolutions of the propellers. *G* are cut-out cocks for shutting off the control valves, as for connecting both turbines to one valve so as to obtain exactly the same speed on both turbines. This stand is located on the bridge and is used in the same manner as the usual mechanical telegraphs. The control valves are connected with the engine room by ¼-inch pipes as shown in Plate II. The engine-room operating stand is practically the same as the one on the bridge, the pipes being connected in parallel through a single-lever operated cut-out valve.

and precise. There is no guesswork as to speed and no revolutions to be counted while manœuvring. This is a valuable feature for either bridge or engine-room operation. It makes

it possible for one man to do what several are required to do with the usual operating gears, and it is done better.

"While steaming, the operating lever is set for the required speed, which is maintained as noted above. It is not necessary for the engineer to stand by the throttle and constantly to regulate the speed. In effect, the human governor is replaced by a mechanical one which is more accurate and better. The engineer of the watch is free to go about the engine-room and see that the machinery is running properly. All that is necessary is that he or some one on watch be near enough to the operating station to answer a signal promptly. This is true when operating from either station. Compare this mechanical regulation with the method employed on naval vessels steaming in formation. Two men, at least, constantly timing and adjusting the revolutions, and nothing else. These two men could be removed entirely or used to better advantage superintending the machinery, which is usually left to less experienced men. The advantage of mechanical regulation is obvious. This feature of the control system is important, and, even if the engines were operated from the engine-room only, would render it desirable.

"In two instances it was necessary to make reverse speed to avoid collision. The steam pressure dropped very low and some of the auxiliaries were about to stop. The engineer protested vigorously against such unwise operation. He, not knowing the danger, would probably have eased up to save steam, and collision would have resulted.

"During one voyage the propellers came out of water so that excessive racing would have occurred with ordinary machinery. Most of the time they came half way out, and frequently they came practically all the way out. Due to the action of the governing mechanism, racing was prevented. The speed increased and decreased slightly—about 4 per cent. estimated. The turbine-inlet valves were opening and closing continuously, and at times they were entirely closed. Quick-operating valves are necessary effectively to prevent racing. This feature of the control system is of importance, because it will enable a vessel to steam at considerable speed in heavy weather."

The bridge control mechanism as applied to the *Neptune* has since been thoroughly revised and modified in a manner to

materially facilitate the accuracy and reliability of operation. An experimental marine turbine and reduction gear has just been erected at the plant of The Westinghouse Machine Company which embodies all features incidental to the recent developments in the Westinghouse marine turbine and reduction gear and the bridge control apparatus. It is believed that this machine will be in operation and open to inspection to those interested in the matter in the course of thirty days, after which time there will doubtless be a thorough technical description of the new features involved.

The thanks of the author are due to The Westinghouse Machine Company for the preparation of the illustrations, to the text-book on steam turbines by Professor Moyer, from which Fig. 17 is taken, and whose outline of the elementary principles of blading has been more or less followed, and to Mr. K. Baumann, of the British Westinghouse Company, from whose paper have been taken almost entirely the correction tables compiled in Appendix III.

(To be continued by Appendices I, II, and III.)

Cause of Dark-colored Nickel Deposits. ANON. (*Brass World*, ix, 1, 27.)—There are several causes of a dark nickel deposit. (1) From too strong current. (2) From the solution becoming alkaline. The articles, if they are of such a shape as to have pockets, carry potash or soda from the cleaning kettle into the nickel-plating bath, if they are not thoroughly removed by rinsing. (3) Stoppage of current. (4) Copper in the nickel solution, arising from articles falling to the bottom of the tank, or from copper in the nickel anodes, or from the copper-plating solution left on the articles to be nickel-plated. (5) Zinc in the nickel solution. (6) Arsenic from impure nickel. The solution should always be slightly acidified with boric acid.

Volcanic Dust in the Atmosphere. ANON. (*Sci. Amer.*, cvii, No. 23, 477.)—Reports of an unusual turbidity of the atmosphere, beginning early last summer, come from various points in Europe and America. There is a marked diminution of the intensity of solar radiation, abnormal displacement of the neutral points of atmospheric polarization, a hazy appearance of the sky, and the presence of Bishop's ring around the sun. There seems reason to attribute these phenomena to the presence in the upper atmosphere of an immense pall of dust arising from the explosive eruption of Katmai volcano, in Alaska, last June.

Case-hardening of Special Steels. A. SAUVEUR and G. A. REINHARDT. (*Trans. Amer. Inst. Min. Eng.*, 1912, 1335.)—Starting with pearlitic steel, by increasing the carbon content or the nickel content, or both, the metal becomes martensitic and eventually austenitic, and remains so after slow cooling,—*i.e.*, it is self-hardening. It should therefore be possible to manufacture case-hardened objects of nickel-steel and of some other special steels having pearlitic,—*i.e.*, soft and tough,—cores, and martensitic or austenitic cases, without quenching. A number of tests made showed the practicability of producing martensitic cases, and, in presence of sufficient nickel, even austenitic cases. Micrographic examination clearly shows the results obtained. An obvious application is the production of tough pieces of machinery with hard wearing surfaces without the distortions and strains produced by quenching.

Band Spectra of Aluminium, Cadmium, and Zinc. EMILY E. HOWSON. (*Astrophysical Journal*, xxxvi, 4, 286.)—The spectra of sun-spots contain many lines and bands which are absent in the spectra of the chromosphere. For instance, the band spectra of *Ca* and *Mg*, often attributed to "hydrides" of these elements, appear strongly in sun-spot spectra. These bands have also been found in the electric arc *in vacuo*, using rods of these elements for the electrodes. Miss Howson has found similar bands in *Al*, *Cd*, and *Zn* arcs burning under reduced pressure. These bands are not present in the arc in air. The wave-lengths of the lines composing these bands were carefully measured and were found to be expressible by a formula of the type $\lambda_m = a+bn+cm_2+dm^3$, where *a*, *b*, *c*, and *d* are constants for a band and *m* an integer representing the number of the line in the series. It will be interesting to see whether or not these bands occur in sun-spot spectra and also if they are true metallic radiations or come from hydrogen compounds of the elements.

Effect of Tension on Metals. HANRIOT. (*Comptes Rendus*, clv, 971.)—The ordinary method of determining the hardness of a metal gives only very imperfect knowledge of its general physical condition, since the latter is altered by the pressure of the sphere in the determination. It was therefore attempted—using sliver, brass, and aluminum—to decide whether tensile tests will give a more reliable figure. It is found, however, that the tension itself produces a hardening effect on soft metals and a softening effect on hard metals. The softer specimens show practically the same load at fracture and the same elongation, and the general effect of the tensile strain is to determine in the metal a certain degree of toughness. The effect does not manifest itself immediately the load is applied, but only appears when permanent deformation occurs.

NOTES FROM THE U. S. BUREAU OF STANDARDS.

ANEROID BAROMETERS.

THE annual Report of the Director of the Bureau of Standards, just published, contains the following statement concerning the Bureau's investigations of aneroid barometers:

Aneroid barometers are instruments of great importance to surveyors, explorers, aviators, and in scientific investigations. The Bureau has undertaken the thorough study of these instruments, which are used to measure the atmospheric pressure and from this to ascertain the altitude above or below sea level. The investigation, which included the intercomparison of a large collection of aneroid barometers representing twelve different makers, was completed during the year. The results show to what extent the errors of an aneroid are physically inherent and to what extent they may be avoided by suitable tests. In the investigation four kinds of tests were made,—namely, mechanical, temperature, atmospheric, and air-pump tests.

The mechanical tests consisted (1) in determining for each aneroid the probable error of a single pointer reading as affected by parallax, tapping, etc., and (2) in calibrating the pressure and altitude scales of typical aneroids.

The temperature tests consisted chiefly in taking aneroids outdoors on a very cold winter night and later heating in a receiver surrounded by hot water, with the conclusion that in good instruments thermal errors are negligible compared with other errors, and therefore need not be seriously considered until more is done to eliminate mechanical and elastic errors.

In the free atmosphere tests 25,000 observations were taken in order to keep track of the history of each aneroid in the interim between successive air-pump tests, to ascertain to what extent it is fair to pass judgment on an aneroid from observations on the fluctuations of its correction from day to day, and to detect secular changes.

The air-pump tests were, however, the most important, and also the most laborious, as it was necessary to hold the aneroids

for 24 hours at the lowest pressure in order to observe the creeping effect due to imperfect elasticity. This determination of the creep appears to be the crucial point in ascertaining the quality of an aneroid.

As a sequel to the foregoing investigation the development of standard specifications for the purchase of aneroids has been undertaken at the joint request of other branches of the Government service and of manufacturers. The final results of the Bureau's work in this field cannot fail to be of great value in improving the design, manufacture, and use of these important instruments.

PHYSICAL TESTING OF COTTON YARN.

W. S. LEWIS, of the Bureau of Standards, completed, in June, 1912, a series of studies and investigations on the effects of various factors, including humidity upon cotton yarns, for the purpose of improving the technical regulations of the trade and developing cotton yarn specifications, as well as to improve methods of testing.

The work consisted of a general consideration of single- and two-ply yarns as to variations in size, twist, and tensile strength of yarns within cops, bobbins, skeins, respectively, etc., and also their behavior under various relative atmospheric humidities.

SUMMARY.

The results of greatest interest ascertained through this investigation and now prepared for publication are as follows:

1. In this series of tests it appears that "two-ply" yarns were nearer the "spinners" number than the "singles" yarns.

2. That "singles" yarns are produced with greater uniformity in size than "two-ply" yarns.

3. It is not more difficult to spin coarse yarns to the required size than fine yarns.

4. Under usual atmospheric changes the size of a 36/1 yarn may vary as much as 2 counts, and an 80/1 yarn over 4 counts, or, in other words, 5.5 per cent. in each case. The "two-ply" yarns are not as susceptible to changes due to humidity in the atmosphere, although they vary from ½ a count

on 10/2 yarn to almost 5 counts on 96/2 yarn, with an average of 4.5 per cent. on all sizes.

5. Under the conditions outlined in No. 4, the yardage in "singles" yarns can be increased or decreased from 1700 to 3700 yards per pound, or 5.5 per cent., according to size of the yarn. The "two-ply" yarns can be changed in yardage by the humidity of the atmosphere, the difference in length ranging between 250 and 2000 yards per pound, or about 4.5 per cent.

6. The irregularity in spinning of the twist in the "singles" yarns is very apparent, but the folding or twisting of two yarns in a "two-ply" yarn can be accomplished with greater uniformity.

7. The tensile strength of yarn depends upon the kind of fibre, length of staple, and its treatment in manufacture. The results of the "lea" method compared with the single-strand method of determining the tensile strength, fully outlined, indicate the superiority of the single-strand method.

8. The tensile strength of cotton yarns increases with an increase of moisture up to 85 per cent. relative humidity (the highest point reached in this investigation). The "singles" yarns are influenced more than the "two-ply" yarns. Calculating from 55 per cent. to 85 per cent. relative humidities, the "singles" increase 17 per cent. and the "two-ply" yarns increase 11 per cent. in tensile strength. Further tests were made with the "two-ply" yarns, and the results show that the strength can be increased more than 16 per cent. between a relative atmospheric humidity of 85 per cent. and a relative atmospheric humidity of 45 per cent.

9. The quantity of sizing in the various makes of "singles" yarns varied from 0.5 per cent. to 1.5 per cent., while the "two-ply" yarns ranged from 1.5 per cent. to 2.5 per cent.

10. The yarn-counts can be determined upon small specimens with an accuracy much greater than it can be manufactured. A 30-yard length is sufficient in determining the size of a yarn, as it was found that the yarn count variation within the cop or bobbin itself is usually much greater than differences found between 120-yard and 30-yard lengths.

THE TESTING AND PROPERTIES OF TEXTILE MATERIALS.

THE Bureau is sending to press a circular which will be of great interest to the textile industry. The textile industry is one of the largest of the manufacturing activities of the United States. The products find their way into both the domestic and foreign markets and form the basis for commercial transactions involving a very large amount of money and affecting every individual consumer. It therefore becomes desirable to have methods of testing which may be applied easily and which will furnish a reliable means for reaching a harmonious agreement between producer, distributer, and consumer. The accurate description of the material and quality, supplemented by an indication of the conditions and methods of test by which it is to be determined, forms a specification upon which it should be possible for the buyer and seller to reach an agreement. For textile materials little standardization has been undertaken, and the industry is dependent very largely upon the units and methods of measurement as carried out by certain manufacturers and individuals.

The study of the physical and chemical properties of textile material by means of laboratory tests has been carried on in this country in a more or less desultory fashion for a great many years. Quite recently, however, the development of more systematic and greatly-improved methods of testing, with a consequent augmented accumulation of data, has given the results obtained a much more practical significance than in former years.

In England, France, Germany, Austria, Italy, and Japan advanced methods of testing have been utilized with remarkable results. The present general interest in the necessity for better methods and standardization of tests has resulted in the establishment of testing apparatus in textile institutions, public testing laboratories, stores, and mills. A large number of samples are submitted to the Bureau of Standards for investigation not only from the Government departments but by manufacturers and dealers. The fact that this work is rapidly increasing is good evidence of the value of the information received. The Bureau will gladly co-operate with institutions, investigators, manufacturers, and consumers, not only in the execution of

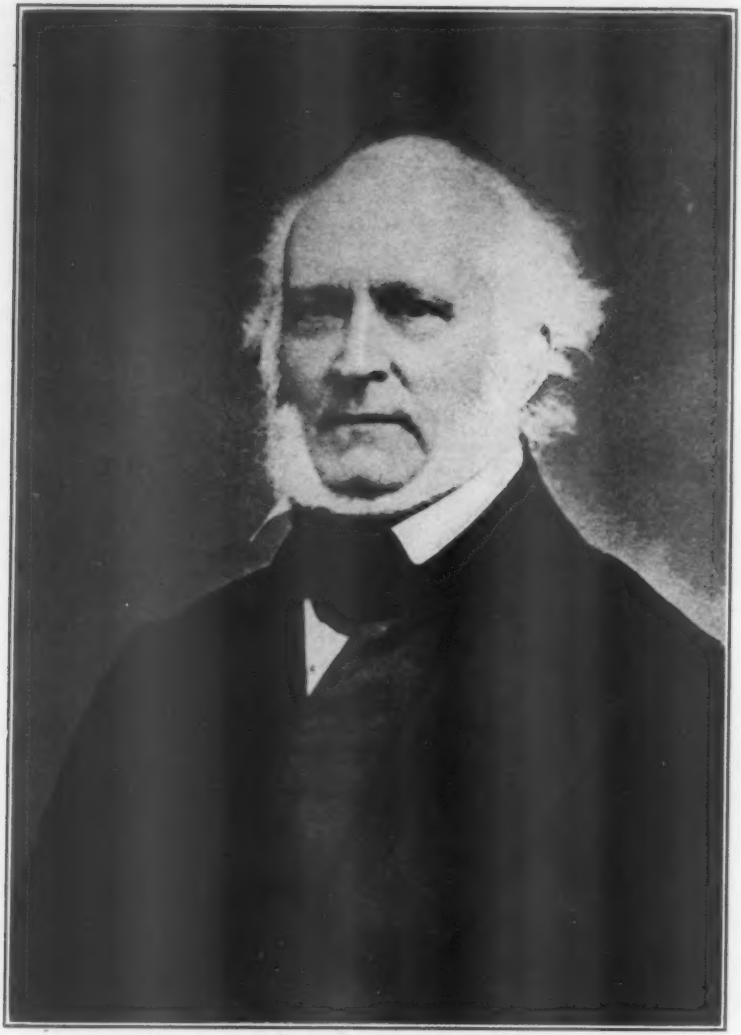
scientific testing and standardization but also in furnishing information in its possession concerning methods of testing and the interpretation of results. It will be pleased, also, to help in the design and construction of special apparatus. The scope of testing which the Bureau is now prepared to undertake is summarized below.

1. *Determinations upon Raw and Unspun Fibres:*
   - (*a*) Indentity of fibre.
   - (*b*) Approximate length.
   - (*c*) Moisture content and "regain."
   - (*d*) Quantity of oil, grease, and foreign substances contained.
   - (*e*) Percentage loss in scouring raw wool.

2. *Determinations upon Yarn, Thread, and Twine:*
   - (*a*) Length.
   - (*b*) Tensile strength and elasticity.
   - (*c*) Count or number.
   - (*d*) Twist.
   - (*e*) Percentage of loading, sizing, and coloring material.
   - (*f*) Percentage fibre composition.

3. *Determinations upon Fabric:*
   - (*a*) Weight.
   - (*b*) Tensile strength and elongation.
   - (*c*) Percentage fibre composition.
   - (*d*) Thread count.
   - (*e*) Yarn number or size.
   - (*f*) Folding endurance.
   - (*g*) Action of light on colors.

Electric-Light Carbons from Tar. ANON. (*Sci. Amer.*, cvii, No. 23, 477.)—High-grade carbons can now be obtained from tar, by a process invented in Sweden. The method depends on the fact that finely-divided carbon forms a large percentage of tar, as the black color is due to carbon particles suspended in an otherwise dense and transparent yellowish-brown liquid. By this process the carbon can be separated from the liquid, and can then be moulded into any desired shape. The powdered carbon can be pressed to form electric-light carbons or into larger sizes for electrodes.



JAMES H. CRESSON.

In memory of whom was recently established, by a friend of the Institute, the "James H. Cresson Memorial Fund" of $50,000. Mr. Cresson was born December 26, 1793, and died February 3, 1880. He was a member of the Institute from 1836 to the time of his death.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, February 19, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 19, 1913.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership since last report, 21.

The standing committees for the year 1913–14 were announced.

Following the meeting of the Institute for the transaction of this business, a joint meeting was held with the Philadelphia Section of the American Institute of Electrical Engineers.

President Clark introduced the speaker of the evening, Prof. Elihu Thomson, of Swampscott, Massachusetts, who presented a paper on the "Transmission of Electrical Energy."

The speaker reviewed the progress made in the electrical transmission of power for lighting and other industrial purposes, telephony, telegraphy, including wireless telegraphy, during the past thirty years and accompanied his remarks by numerous experimental illustrations of a novel and striking kind. He referred to the fact that the parallel coupling of alternating current transformers was first done in the Hall of the Institute in 1879 and exhibited replicas of these transformers in operation. A simple and elegant explanation was given of the fact that electromagnetic waves used in wireless telegraphy follow the earth's curvature. In referring to the possibilities of transmission by direct currents of high voltage the speaker exhibited a new form of static machine, the revolving parts of which consisted of aluminum wings stoutly attached to insulated hubs, the glass portion being stationary. This machine operates on the Wimshurst principle, but has the advantage of being a thoroughly mechanical piece of apparatus.

After a vote of thanks to the speaker the meeting adjourned.

R. B. OWENS,
Secretary.

STANDING COMMITTEES, 1913,

Of the Board of Managers.

INSTRUCTION.

Lawrence T. Paul, *Chairman,*
Charles Day,
George A. Hoadley,
E. V. McCaffrey,
James S. Rogers.

ELECTIONS AND RESIGNATIONS.

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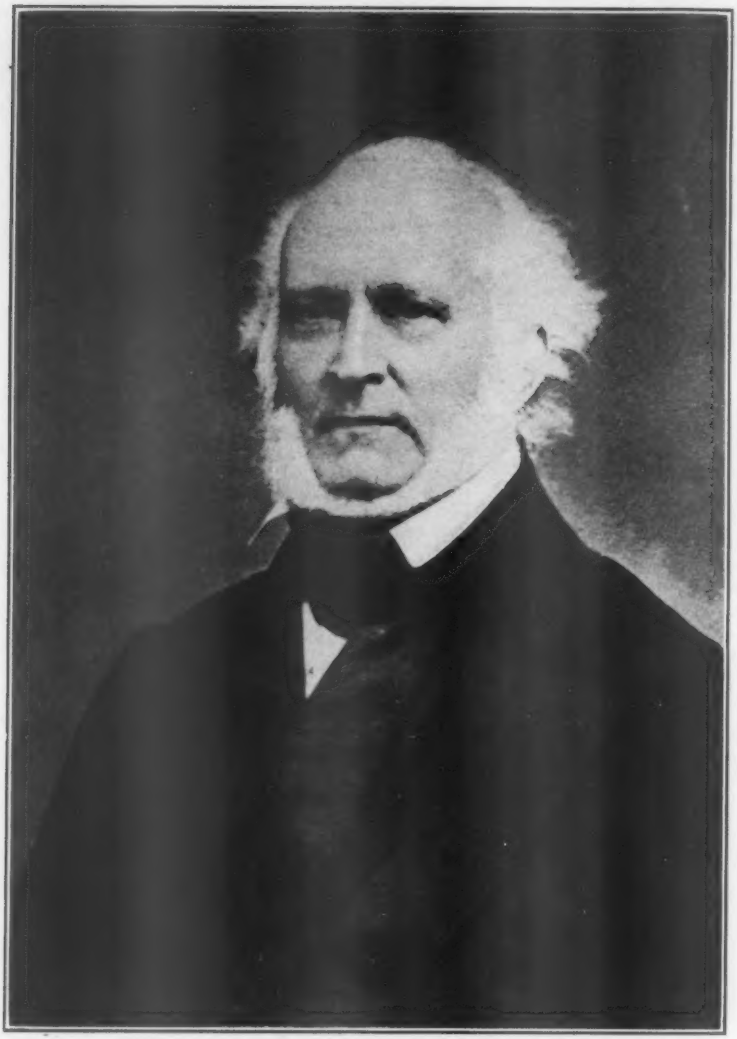

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Robert S. Perry,
Alexander P. Robinson.

STOCKS AND FINANCE.

Walton Forstall, *Chairman,*
Cyrus Borgner,
Alfred C. Harrison,
Richard Waln Meirs,
E. H. Sanborn.

PUBLICATIONS.

Louis E. Levy, *Chairman,*
John Birkinbine,
W. C. L. Eglin,
George A. Hoadley,
E. H. Sanborn.

EXHIBITIONS.

John Birkinbine, *Chairman,*
Francis T. Chambers,
James M. Dodge,
W. C. L. Eglin,
C. A. Hexamer.

SECTIONAL ARRANGEMENTS.

Charles Day, *Chairman,*
Francis T. Chambers,
W. C. L. Eglin,
Louis E. Levy,
Lawrence T. Paul.

ENDOWMENT.

Henry Howson, *Chairman,*
James M. Dodge,
Alfred C. Harrison,
Richard Waln Meirs,
Coleman Sellers, Jr.

EXECUTIVE.

E. H. Sanborn, *Chairman,*
James M. Dodge,
Walton Forstall,
Alfred C. Harrison,
Richard Waln Meirs.

Of the Institute.

LIBRARY.

N. W. Akimoff,
E. V. d'Invilliers,
Richard Gilpin,
Clarence A. Hall,
Harry F. Keller,
Gaetano Lanza,
Henry Leffmann,
Louis E. Levy,
George F. Stradling,
John C. Trautwine, Jr.

MEETINGS.

G. S. Barrows,
G. H. Clamer,
George R. Henderson,
H. A. Hornor,
Herbert E. Ives,
M. M. Price,
James S. Rogers,
Geo. D. Rosengarten,
Coleman Sellers, Jr.,
C. C. Tutwiler.

MUSEUMS.

Henry F. Colvin,
Charles Day,
James M. Dodge,
Richard Gilpin,
George A. Hoadley,
H. F. Keller,
Wilfred Lewis,
A. E. Outerbridge, Jr.,
Wm. H. Thorne,
Wm. J. Williams.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, February 5, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 5, 1913.

Mr. J. A. P. Crisfield was elected Chairman for the year 1913, and occupied the chair.

The following report was presented for first reading:

No. 2523.—Ellis Adding Typewriter.

The following were accepted for examination:

No. 2524.—The Applications of the Gyroscope to Marine Purposes. Elmer A. Sperry.

No. 2526.—C. Francis Jenkins' Motion Picture Apparatus.

No. 2527.—Norton Alundum Refractories.

No. 2528.—Non-Toxic Bactericide "Pyxol."

No. 2529.—The Work of Albert Sauveur in Connection with the Metallography of Iron and Steel.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the section was held in the Hall of the Institute on Thursday evening, January 30, 1913, at 8 o'clock.

Dr. George A. Hoadley occupied the chair.

The Chairman introduced Dr. Edward P. Hyde, Director of the Physical Laboratory, National Electric Lamp Association, Cleveland, Ohio, who read an interesting paper on "The Physical Laboratory of the National Electric Lamp Association—A *Résumé* of the Activities of the Laboratory in the Development of the Modern Science of Illumination."

After an introduction reviewing the organization of the illuminating engineers of this country and abroad and the development of the profession by the application of the work of physicists, physiologists, and psychologists, Dr. Hyde described the building and equipment of the present laboratory of the National Electric Lamp Association and the work done there during the past four years.

With the aid of lantern slides he described the new laboratory now nearing completion in the suburbs of Cleveland. The thanks of the meeting were extended by Dr. Hyde.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

Mining and Metallurgical Section.—A meeting of the section was held on Thursday evening, February 13, 1913, at 8 o'clock, in the Hall of the Institute.

The meeting was called to order by the president of the section, Professor A. E. Outerbridge, Jr.

With a few apt remarks on the extraordinarily rapid growth of the science of Metallography and on the already extensive practical application of its principles in the field of iron and steel manufacture, the Chairman introduced Mr. Albert Sauveur, B.S., Professor of Metallurgy and Metallography, Harvard University, who delivered an illustrated lecture entitled "An Outline of the Metallography of Iron and Steel."

Professor Sauveur showed an interesting series of photo-micrographs, depicting the proximate composition of pure iron, cast and wrought iron, cast steel, etc. With the aid of these pictures he defined the terms used in metallography. He then showed curves and explained critical temperature, annealing, tempering, etc.

His remarks illustrated clearly what had been done in the field of metallography during the past twenty years, since the science had begun its present era of development and application.

After a brief discussion, the thanks of the meeting were extended Professor Sauveur.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

CAMP LIFE IN PHILADELPHIA.

Mr. W. N. Jennings, member, delivered a lecture bearing the above title on Thursday evening, February 6, 1913, in the Hall of the Institute.

With the aid of numerous lantern slides made from his own photographs Mr. Jennings described how for four months in the year his family reaps the benefit of sunlight and fresh air at his camp situated on picturesque ground within the city limits.

The lecture was well attended, and the audience showed marked appreciation of Mr. Jennings's very interesting pictures.

ON THE EDGE OF ALASKA.

A lecture bearing the above title and illustrated by 150 beautifully-colored lantern photographs was delivered by Dr. George Flowers Stradling, member, on Friday evening, January 31, 1913, in the Hall of the Institute.

Many of the pictures shown were taken by Dr. Stradling when on a visit to this remarkable country last summer, the remainder being loaned by Mr. Clark, for two years a resident in Alaska.

The reproduction of the color effects in some of the glacier and sunset scenes shown was remarkably true to nature, and the audience was well able to obtain a very representative idea of the features of this interesting country.

MEMBERSHIP NOTES.

Elections to Membership.

(Stated meeting of the Board of Managers, February 13, 1913.)

RESIDENT.

MR. HENRY I. BROWN, 435 Walnut Street, Philadelphia, Pa.
MR. WM. D. DISSTON, Disston Saw Works, Tacony, Philadelphia, Pa.
MR. C. H. GEIST, Land Title Building, Philadelphia, Pa.
MR. EDWIN M. GOLDSMITH, Friedberger-Aaron Mfg. Co., Logan Station, Philadelphia, Pa.
MR. JOHN L. HAND, 222 Walnut Street, Philadelphia, Pa.
DR. JOSEPH HEAD, 1500 Locust Street, Philadelphia, Pa.
MISS EMILY E. HOWSON, 109 North Thirty-fourth Street, Philadelphia, Pa.
MR. J. C. JOHNSON, Superintendent Telegraph, Pennsylvania Railroad Company, Broad Street Station, Philadelphia, Pa.
MR. LIONEL FARADAY LEVY, 1424 North Fifteenth Street, Philadelphia, Pa.
DR. PAUL A. LEWIS, Director of Laboratory, The Henry Phipps Institute, University of Pennsylvania, Philadelphia, Pa.
HON. JAMES P. MCNICHOL, 222 North Nineteenth Street, Philadelphia, Pa.
MR. W. H. MARSHALL, United Gas Improvement Company, Broad and Arch Streets, Philadelphia, Pa.
MR. J. WALTER MILES, Irwin, Pa.
MR. CLEMENT D. RINALD, 1142 North Hancock Street, Philadelphia, Pa.
MR. EDWARD RITTENHOUSE, Linwood, Delaware County, Pennsylvania.
MR. WILLIAM C. WETHERILL, 307 West Springfield Avenue, St. Martin's, Philadelphia, Pa.

NON-RESIDENT.

MR. EDWIN DURYEA, JR., 1314 Humboldt Bank Building, San Francisco, Cal.
LIEUT. R. E. GILLMORE, Sperry Gyroscope Company, 74 Broadway, New York, N. Y.
MR. A. DW. SMITH, Coal Exchange Building, Wilkes-Barre, Pa.
MR. LEON E. THOMAS, Birdsboro Steel Foundry and Machine Company, Birdsboro, Pa.
MR. CHRISTOPHER WREN, Plymouth, Pa.

Changes of Address.

DUGALD CLERK, F. R. S., 58, Lincoln's Inn Fields, London, W. C., England.
MR. WALTER COX, Pennsylvania Wire Glass Company, Pennsylvania Building, Philadelphia, Pa.
MR. EDWARD V. D'INVILLIERS, 506 Walnut Street, Philadelphia, Pa.
MR. WALTER H. FULWEILER, 1706 North Broad Street, Philadelphia, Pa.
MR. RADCLYFFE FURNESS, Midvale Steel Company, Philadelphia, Pa.
MR. B. SPENCER GREENFIELD, 4420 Fleming Street, Roxborough, Philadelphia, Pa.

MR. ARTHUR C. JACKSON, 6445 Greene Street, Germantown, Philadelphia, Pa.
MR. J. P. JEFFERSON, Warren, Pa.
MR. MALCOLM R. MACLEAN, American Steel Foundries, Pittsburgh, Pa.
MR. JOHN WIEGAND, 1931 North Seventh Street, Philadelphia, Pa.
DR. FRANCIS WYATT, 402 West Twenty-third Street, New York City.

NECROLOGY.

Mr. John Fritz, 155 Market Street, Bethlehem, Pa.

LIBRARY NOTES.

Purchases.

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